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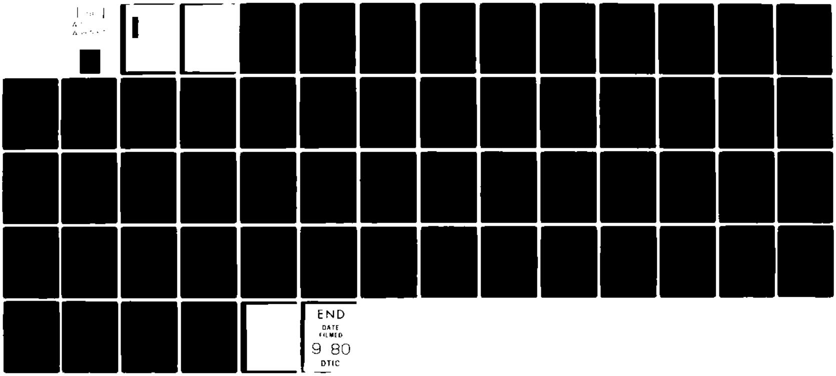

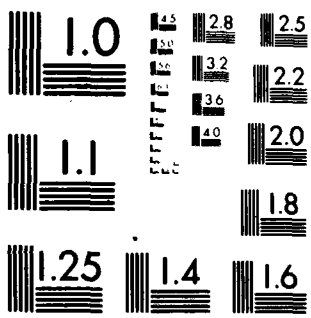

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The possibility of modifying an existing fighter aircraft to give it V/STOL capability and of incorporating a V/STOL control system that could also be used in conventional flight to improve the aircraft's combat maneuverability is examined. The study indicates that the F-18 could by given a V/STOL capability using either the lift plus lift-cruise or the vertical attitude take off and landing (VATOL) concept. The lift-cruise plus remote

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burner concept does not appear to be compatible with the F-18 airframe. The ADEN nozzle concept currently under development, with some modification, could be used on either the lift plus lift-cruise or the VATOL concepts to vector the cruise engine thrust and thereby augment the conventional controls for improved high angle of attack combat maneuverability.

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ABSTRACT

The possibility of modifying an existing fighter aircraft to give it V/STOL capability and of incorporating a V/STOL control system that could also be used in conventional flight to improve the aircraft's combat maneuverability is examined. The study indicates that the F-18 could be given a V/STOL capability using either the lift plus lift-cruise or the vertical attitude take off and landing (VATOL) concept. The lift-cruise plus remote burner concept does not appear to be compatible with the F-18 airframe. The ADEN nozzle concept currently under development, with some modification, could be used on either the lift plus lift-cruise or the VATOL concepts to vector the cruise engine thrust and thereby augment the conventional controls for improved high angle of attack combat maneuverability.

ADMINISTRATIVE INFORMATION

This study was completed for the David W. Taylor Naval Ship Research and Development Center (DTNSRDC) under Navy contract N00167-80-M-0844. Mr Kuhn was engaged in V/STOL aircraft research with the NASA Langley Research Center for many years. He now serves as a V/STOL consultant to both industry and government.

INTRODUCTION

This brief conceptual study examines two related ideas; the possibility of modifying an existing fighter to give it V/STOL capability and the possibility of designing the modifications so that the V/STOL controls can be used to augment the conventional controls and improve the combat maneuverability. The study has not been conducted in depth but is a "first cut" intended to examine the modifications required and to give a qualitative evaluation of the risk and development effort required.

V/STOL

The development of V/STOL is caught in a catch 22 situation. There is little that remains to be done in the laboratory that will significantly affect the decision of whether and where to use V/STOL capability. What is needed now is operational experience to show how the capability can be used, to determine what its payoffs can be, and to develop specific requirements. But operational experience cannot be obtained without operating aircraft and the very high cost of developing new aircraft make it virtually impossible to justify development of an aircraft for a role where the operational employment can only be visualized and the requirements cannot be justified on the basis of experience.

Frequently in the past, aircraft designed and developed for one type of operation have been modified to fill a different need rather than to build a totally new aircraft for the new job. The present very brief conceptual study examines the possibility of modifying an existing first line fighter, in this case an F-18, to give it V/STOL capability.

Three V/STOL concepts were initially included in the study: lift plus lift-cruise, vertical attitude, and a lift-cruise, plus remote burner system. One objective of the study was to determine the modifications that would be required with each V/STOL concept and to qualitatively evaluate the complexity and risk of these modifications and to indicate the development effort required.

COMBAT MANEUVERABILITY ENHANCEMENT

Several simulation studies[1-3*] have indicated that combat capability could be greatly improved by augmenting the conventional aerodynamic controls at high angles of attack. Reference 3 indicates that the level of control normally used for V/STOL operation is sufficient. The other primary objective of this study was to incorporate V/STOL controls that could also be used in conventional flight to augment the conventional control for improved high angle of attack maneuverability.

OVERVIEW OF CONCEPTS

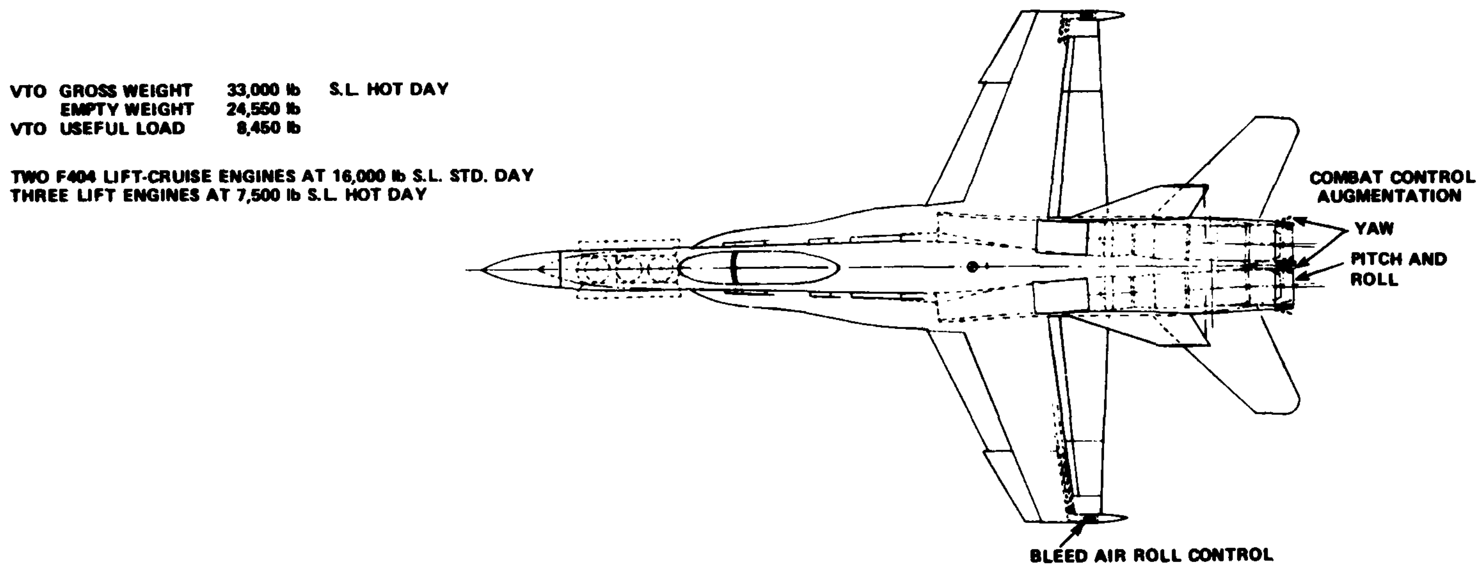
LIFT PLUS LIFT-CRUISE

The general arrangements of the two lift plus lift-cruise configurations considered are shown in Figure 1. The axisymmetric nozzles on the existing cruise engines are replaced with ADEN nozzles to deflect the thrust to the vertical.

Because of the large moment arm of the deflected thrust of the lift-cruise engines the lift engines in the original configuration (Figure 1a) were placed as far forward as possible to minimize the size required. The radar section was kept intact and moved forward about 4 feet and a new connecting section containing the lift engines inserted between the radar section and the cockpit. The gun would have to be moved; probably behind and beside the cockpit with the gun barrel in a blister on the side of the fuselage or in the leading edge extension (LEX).

*A complete listing of references is given on page 49.

Figure 1 - General Arrangement of Lift Plus Lift-Cruise Concept



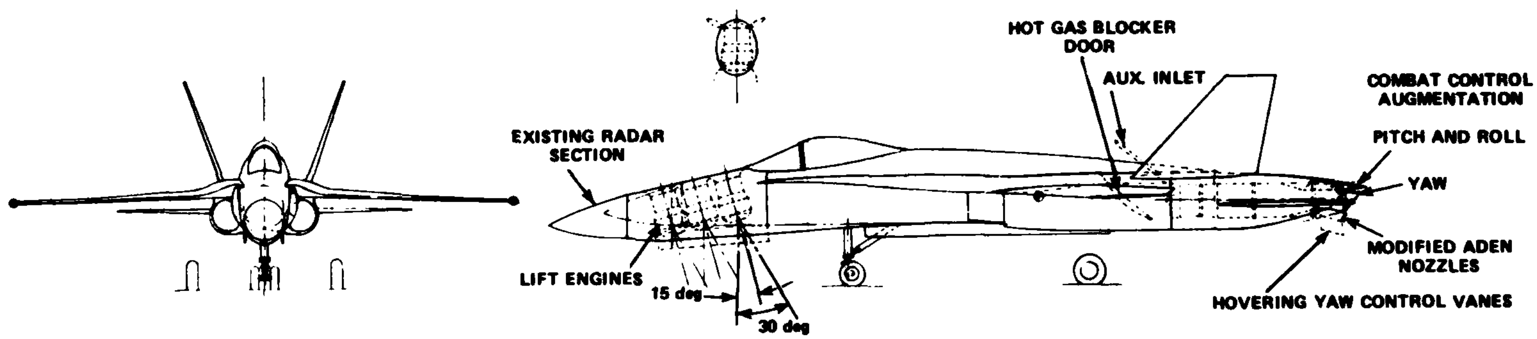


Figure 1a - Lift Engines Ahead of Cockpit

Figure 1 (Continued)

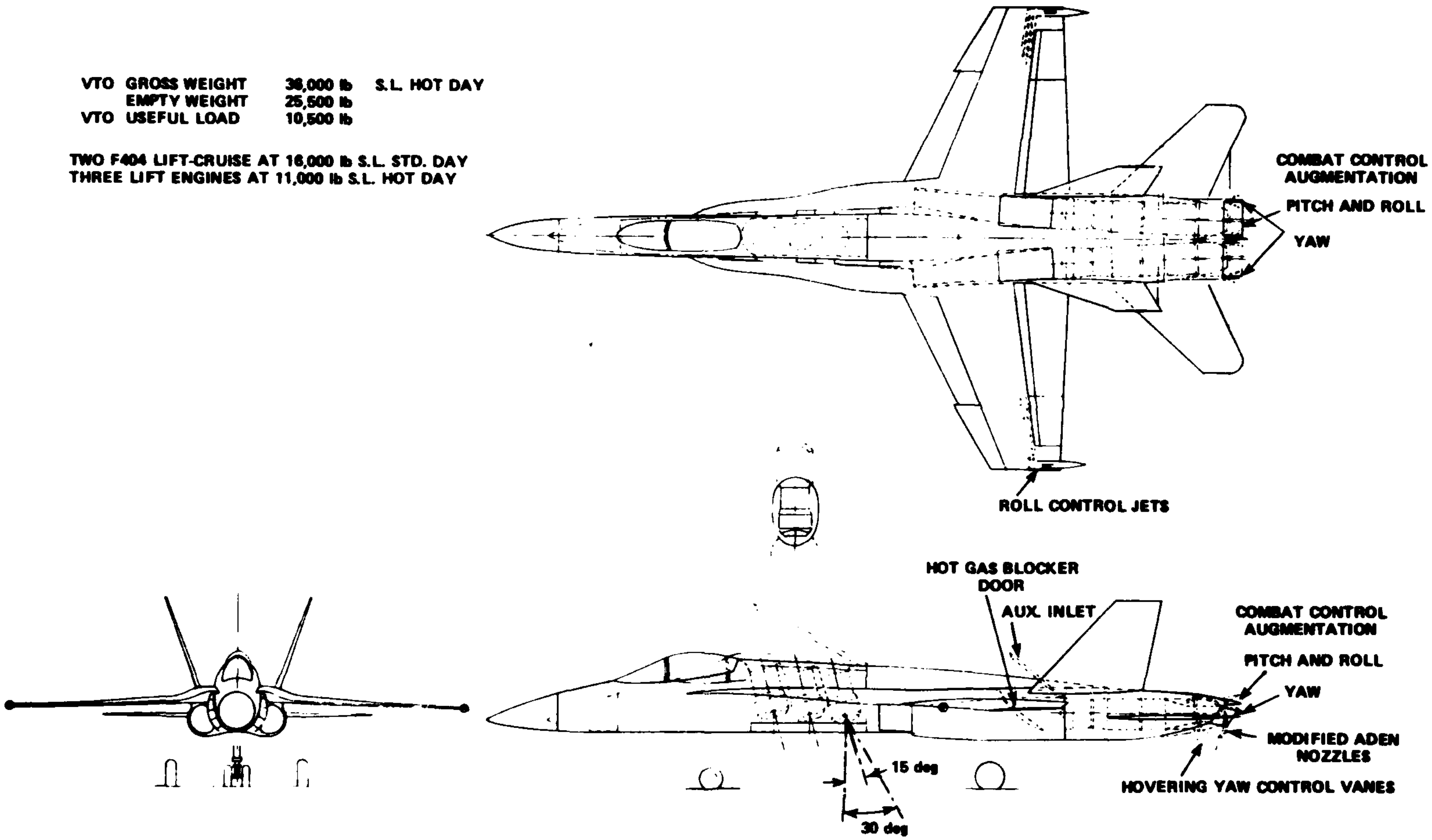


Figure 1b - Lift Engines Behind Cockpit

Because of the very large adverse ground effects estimated for the original configuration (Figure 1a) and concern about the nose wheel temperature environment the configuration was revised as shown in Figure 1b. The fuselage was separated at the production break aft of the cockpit and the radar, gun, and cockpit sections are moved forward 5 feet. The lift engines are installed behind the cockpit. Three engines are used to keep them small enough to stay within the aerodynamic lines. Installation of the lift engines behind the cockpit also permits operating the lift-cruise engines dry, thus somewhat moderating the deck temperature environment by avoiding the extreme temperatures involved with afterburner operation.

Hot gas ingestion by the lift-cruise engines is minimized by blocking the main inlet duct with a section of the top of the duct hinged to deflect downward into the duct. Large auxiliary inlets are installed on the top of the fuselage to provide the total inlet area required for V/STOL operation.

Pitch control is obtained by differential thrust modulation of the lift and the lift-cruise engines. Roll control in V/STOL operation is provided by bleed air from the lift engines ducted to roll control nozzles at the wing tips. Yaw control is obtained by lateral deflection of the lift-cruise engine thrust using auxiliary surfaces hinged to the sides of the ADEN nozzles. Transition and STOL operation are facilitated by rearward deflection of the lift engine thrust and by vectoring of the lift-cruise engine thrust by the ADEN nozzle.

Bleed air and differential thrust modulation are not available in conventional flight for combat maneuverability enhancement, however, the variable external expansion ramp (VEER) on the two ADEN nozzles can be used together for pitch control augmentation, and differentially for roll control augmentation. Yaw control augmentation is obtained by lateral deflection of the thrust.

LIFT-CRUISE PLUS REMOTE BURNER

This concept assumes that the fan flow from a low bypass-ratio turbofan engine is collected and ducted to a remote burner. The remote burner and nozzle are placed forward to provide a lift vector to balance the deflected thrust from the ADEN nozzles on the engines. The general arrangement, shown in Figure 2, is similar to the initial lift plus lift-cruise concept with the remote burner and nozzle substituted for the lift engines in the new bay forward of the cockpit.

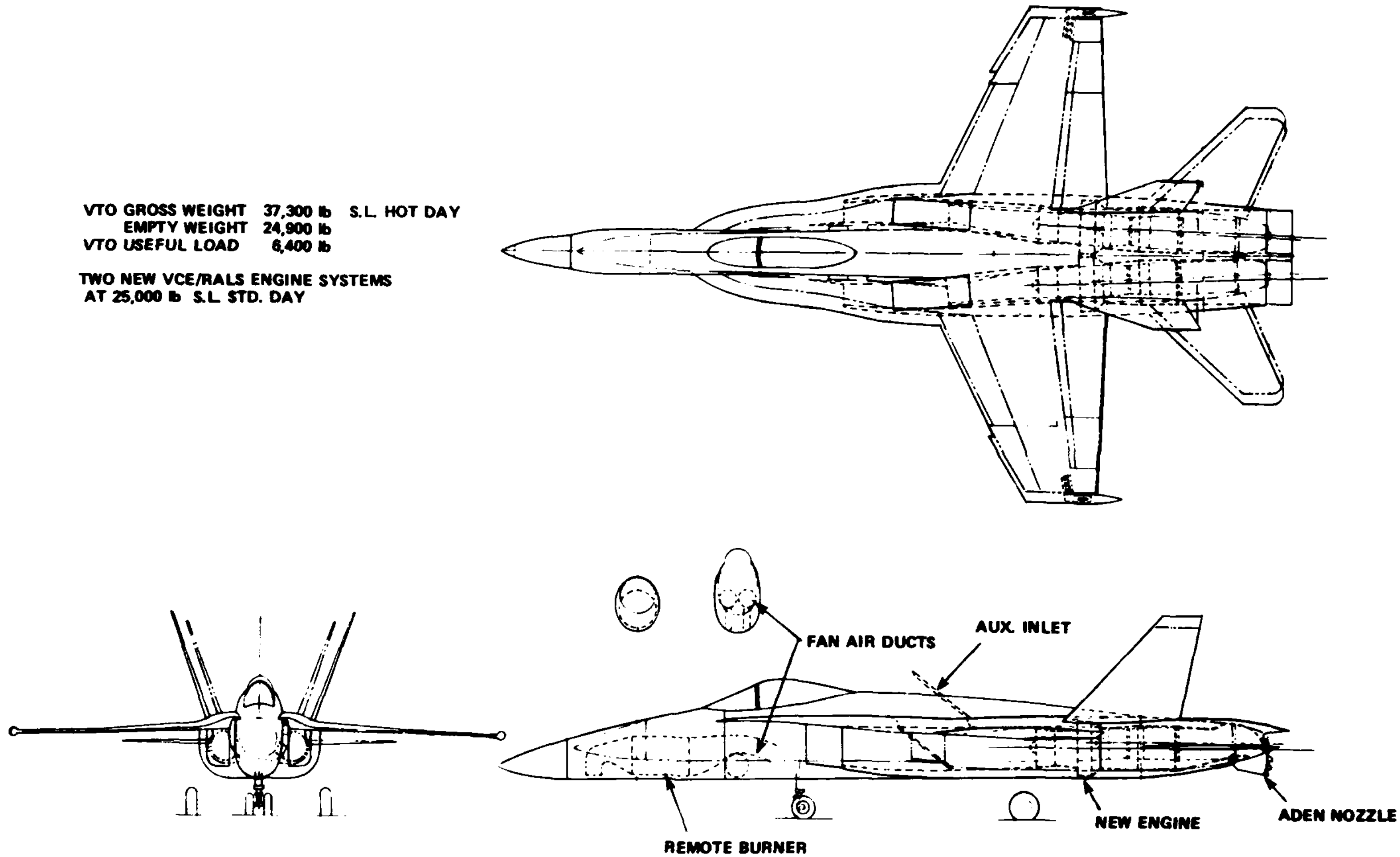


Figure 2 - General Arrangement of Lift-Cruise Plus Remote Burner Concept

Estimates of the vertical lift available from the existing engines modified to the remote burner concept indictated that (after allowances for a hot day, inlet and nozzle losses, hot gas ingestion and aerodynamic ground effect losses, and attitude and height control allowances) the vertical lift would not exceed the empty weight of the aircraft. New larger engines would be required and these would require a complete rebuilding of the fuselage.

Because of the extent of the modifications required, the remote burner concept was not pursued further in this study. This V/STOL concept appears better suited to a new design than to the modification of an existing aircraft of the type studied here.

VECTORED THRUST

The vectored thrust concept such as employed on the AV-8 Harrier was not investigated because of its obvious incompatability with the basic airframe being considered for modification. The vectored thrust like the remote burner concept appears better suited to a new design.

VATOL

Because the VATOL concept involves a unique operational mode involving flying the airplane through the stall and progressively tilting the pilot so that adequate visual cues can be maintained, an operational research and development* aircraft is required to explore these problems as they apply to service pilots in fleet operations, to develop and demonstrate solutions, and to determine the operational feasibility and limitations of the VATOL concept[4]. Therefore, conceptual layouts of both an operational and R and D aircraft and a potential fighter are presented in Figure 3. Except for the cockpit the general arrangement of the two configurations are the same.

Dual axis gimbaled nozzles (or special modified ADEN nozzles) are installed on the engines to provide control in V/STOL operation and to augment conventional control for combat maneuverability. The nozzles deflect the thrust laterally for yaw control and vertically for pitch control. Thrust is deflected differentially in the vertical plane for roll control.

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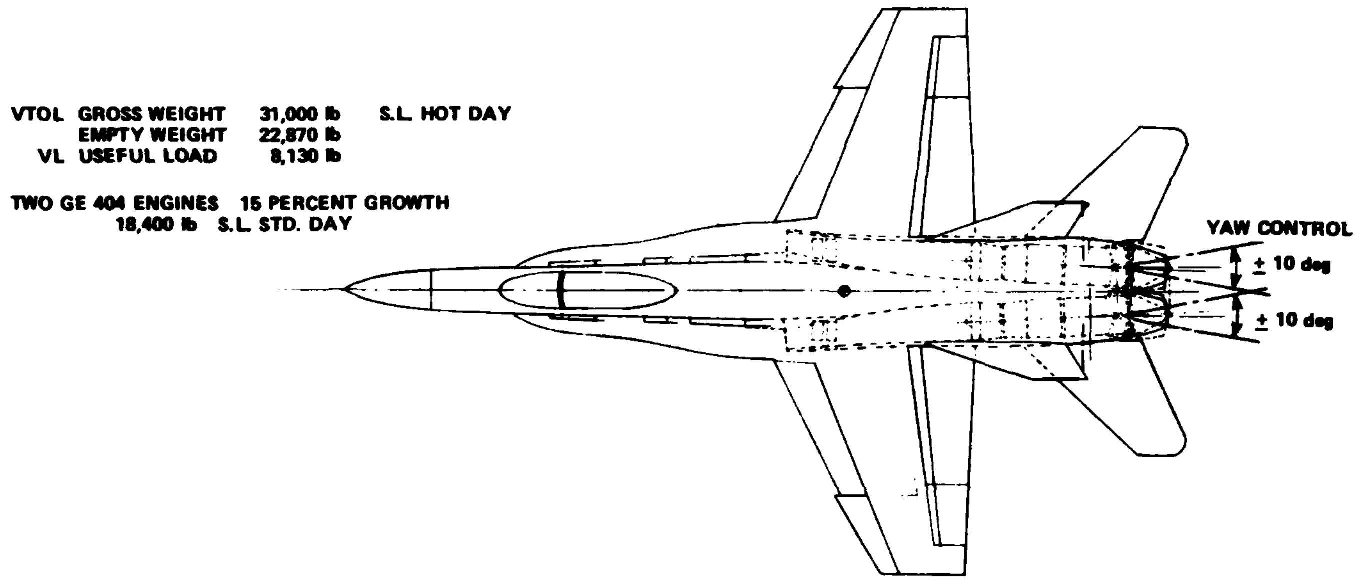
*Research and development shall hereafter be abbreviated as R and D.

Figure 3 - General Arrangement of VATOL Concept



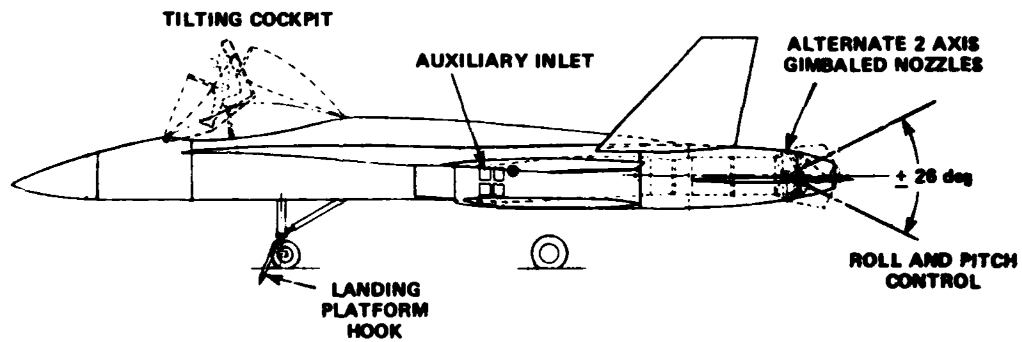


Figure 3a - Fighter

Figure 3 (Continued)

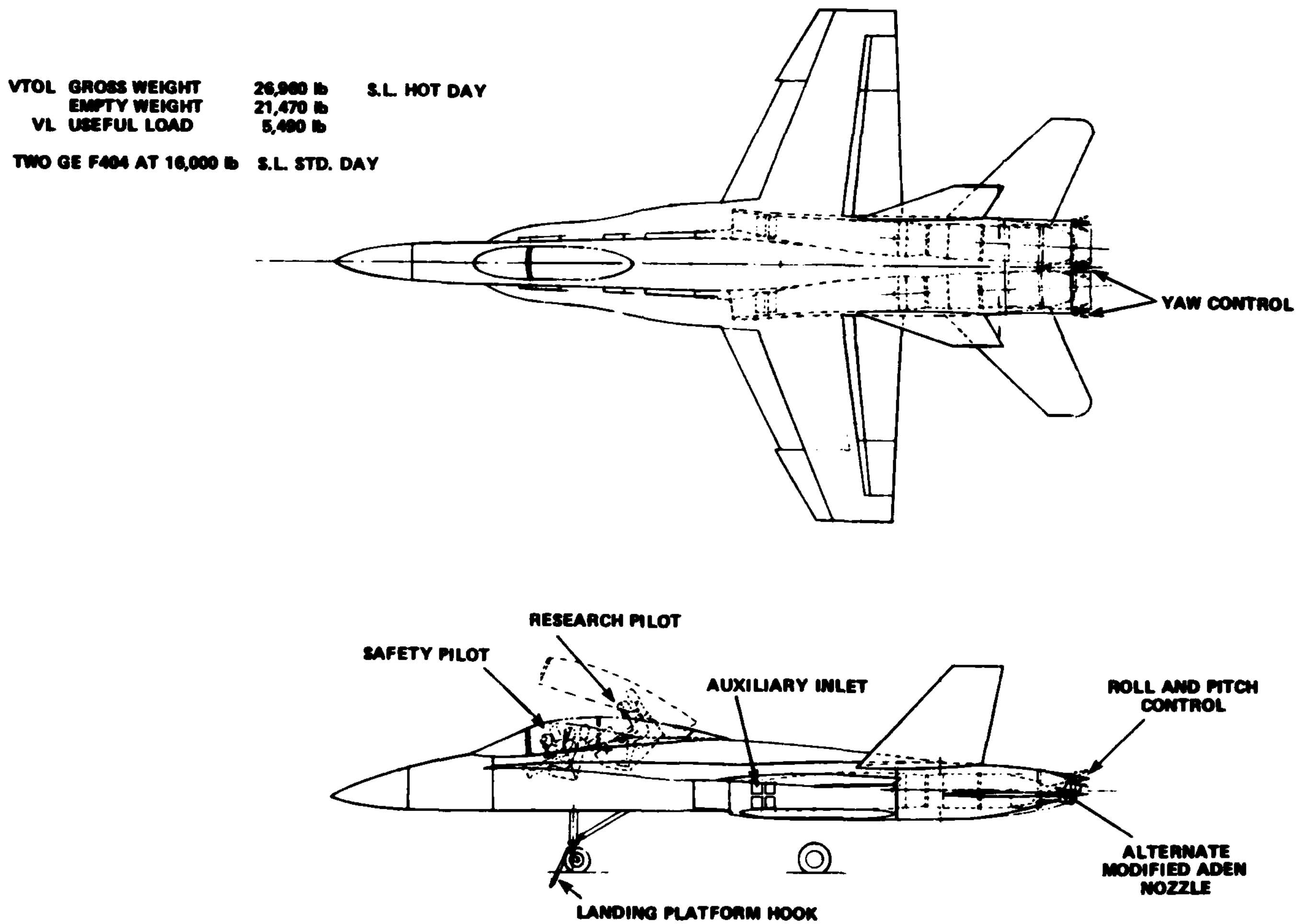


Figure 3b - Operations Research and Development Aircraft

Blow-in doors are added to the inlet to provide the additional inlet area required for good static thrust. The catapult launch arm on the nose gear is replaced by a special hook to engage the landing platform for VATOL operation. A tilting cockpit or seat is provided to minimize the problem of the pilot "lying on his back" and to give him reasonable visual cues during vertical operation.

V/STOL PERFORMANCE AND CONTROL

LIFT PLUS LIFT-CRUISE

VTOL Lift

The vertical lift available in a V/STOL aircraft is always considerably less than the rated engine thrust because of the various installation losses and allowances. Experimental data on the specific configuration are needed to determine most of these losses; particularly ground effects and hot gas ingestion. The current estimates are based on interpretation of limited available data and on estimating methods. These losses are summarized in the estimate of the VTOL gross weight presented in Table 1.

TABLE 1 - THRUST LOSSES AND ALLOWANCES FOR THE LIFT PLUS LIFT-CRUISE CONFIGURATION

Thrust (lb)	2-GE F404	3-Lift at 11,000
Rated	22,000 Dry	33,000 Hot Day, bleed
Hot Day	21,230	33,000
After Hot Gas Ingestion (15 C)	19,744	30,690
After Installation Losses		
Inlet, Nozzle and Base	17,960	29,090
After Trim, Control and		
Ground Effect Allowances	11,855	24,145
VTOL Gross Weight (lb)	36,000	

Inlet temperature rise is one of the most difficult factors to estimate. It has been assumed that operating techniques and the configuration (main inlets blocked and auxiliary inlets over the wing) would limit the inlet temperature rise in both the lift and lift-cruise engines to 15°C. Inlet and nozzle losses are taken as 1 percent and 2 percent, respectively, for the lift engines and 2 percent and 5 percent, respectively, for the lift-cruise engines.

Ground effect was estimated by an unpublished method currently being developed in a separate effort and is presented in Figure 4. The very large suckdown with the lift engines ahead of the cockpit is due to the relatively large wing area and the

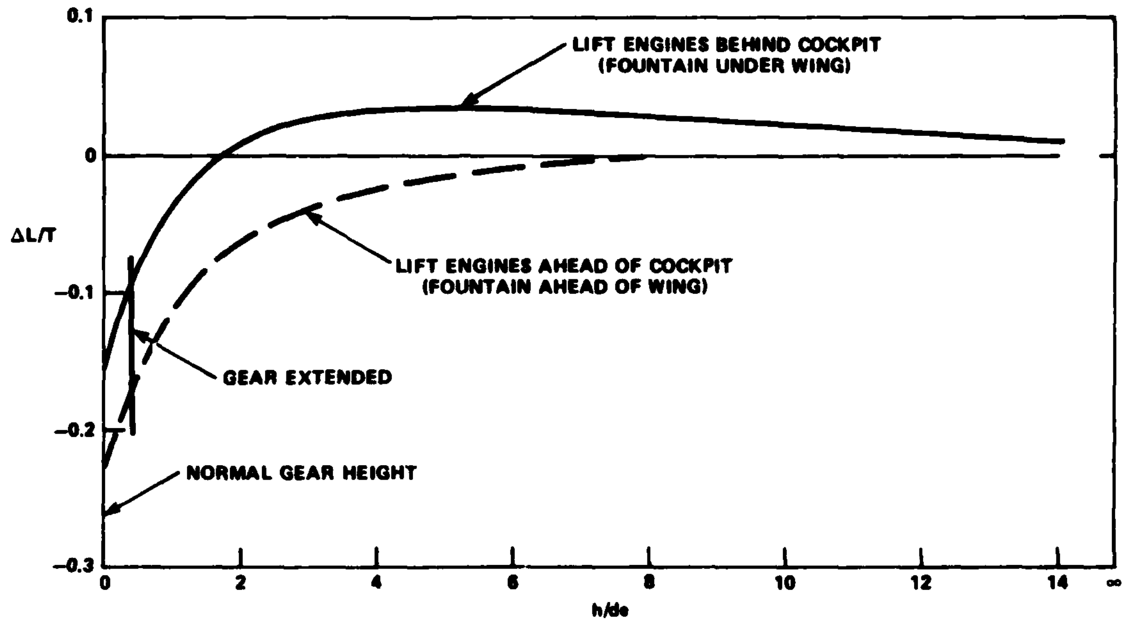


Figure 4 - Estimated Ground Effects of Lift Plus Lift-Cruise Configurations

fact that the fountain flow from the interaction of the lift and lift-cruise engine exhaust flows occurs ahead of the wing and thus only the part that impinges on the fuselage acts to offset the suckdown on this configuration. With the lift engines behind the cockpit the fountain flow occurs under the wing and produces a favorable ground effect at the higher heights although the losses are still large at normal gear height.

The variation of the thrust required from the lift and from the lift-cruise engines with height for trimmed hovering flight is shown in Figure 5. For this configuration the lift margin available for vertical acceleration and the pitch control capability are determined by the excess thrust available from the lift engines. (Even with the lift-cruise engines operating at dry power the thrust available is greater than that required for trim.) The pitch control and vertical acceleration

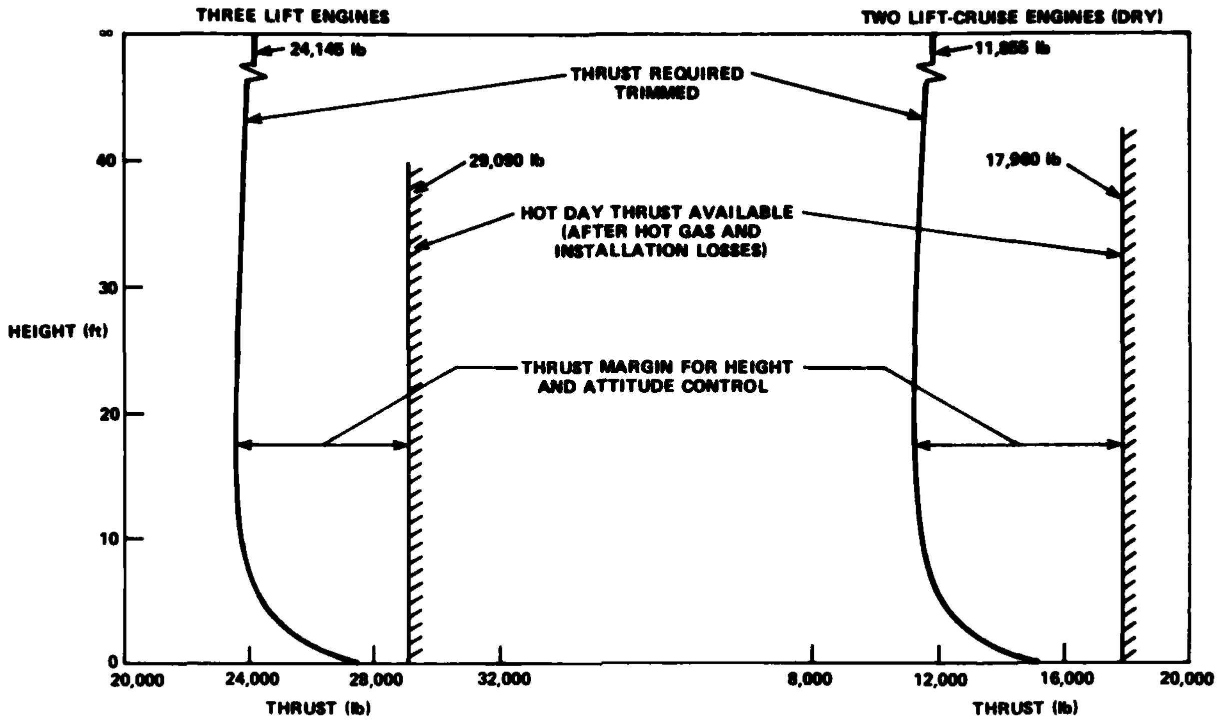


Figure 5 - Hovering Thrust Required, Lift Plus Lift-Cruise Configuration, W = 36,000 Pounds

available as a function of height is presented in Figure 6. A vertical acceleration of 0.06 g's is available with the airplane at rest on the ground. Before the nose gear is fully extended, the vertical acceleration exceeds 0.1 g and pitch control exceeds 0.6 radians per square second, 50 percent more than the minimum required for maneuver.

Weight

A preliminary estimate of the effect of the modifications on the aircraft empty weight is presented in Table 2. The estimates of the weights of modifications are based on the statistical methods of Reference 5, on examination of the weight statements of several current high performance fighters and design studies of proposed V/STOL fighters. The lift engine weights are based on technology of the XJ-99 engine. The estimate of the probable useful load and fuel available is shown in Table 3.

Some weight can be saved by deleting the arresting gear tail hook and substituting a conventional gear for the high sink speed carrier gear. The net result of

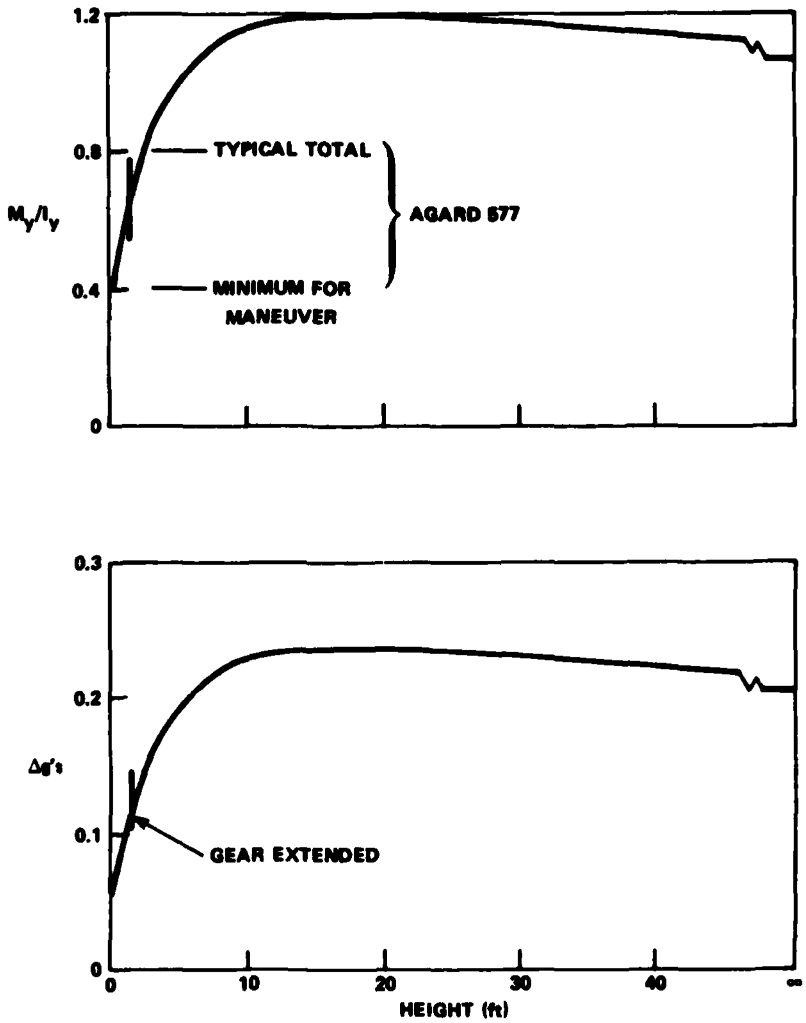


Figure 6 - Pitch Control and Vertical Acceleration Available, Lift Plus Lift-Cruise Configuration, W = 36,000 Pounds

TABLE 2 - WEIGHT ESTIMATE FOR THE LIFT PLUS LIFT-CRUISE CONFIGURATION

F-18 Empty Weight (lb)		21,800
Delete Tail Hook	-171	
Substitute Conv. Landing Gear	-363	-534
Add; Lift Engines $\alpha T/W=15.3$	2157	
Installation	431	
Lift Engine Nozzles	395	
ADEN Nozzles	670	
Roll Control System	110	
Auxiliary Inlet	100	
Lengthen Fuselage	286	+4,149
VTOL Empty Weight (lb)		25,415

TABLE 3 - FUEL AVAILABLE FOR THE LIFT PLUS LIFT-CRUISE CONFIGURATION

Useful Load Available-VTOL (lb)		10,585
Mission Items (lb)		
Crew and equipment	261	
Missiles, gun, etc.	2191	
Oil and unusable fuel	600	
Reserve fuel	1000	
		4,052
Fuel Available (lb)		6,533

the modifications, however, is an empty weight increase of about 3600 pounds. The useful load in the VTOL mode is, therefore, reduced to about 10,500 pounds. Much greater loads can be carried in the short takeoff (STO) mode as will be discussed later.

Because the radar, gun, and cockpit sections are moved forward and because most of the added weight is forward, the center of gravity (C.G.) will move forward about a foot or 0.08 percent of the mean geometric chord.

Thrust Required in Transition

The division of thrust between the lift and the lift-cruise engines for trimmed steady level flight in the transition speed range is shown in Figure 7 along with the nozzle deflections required. The approach configuration consisting of 30 degrees

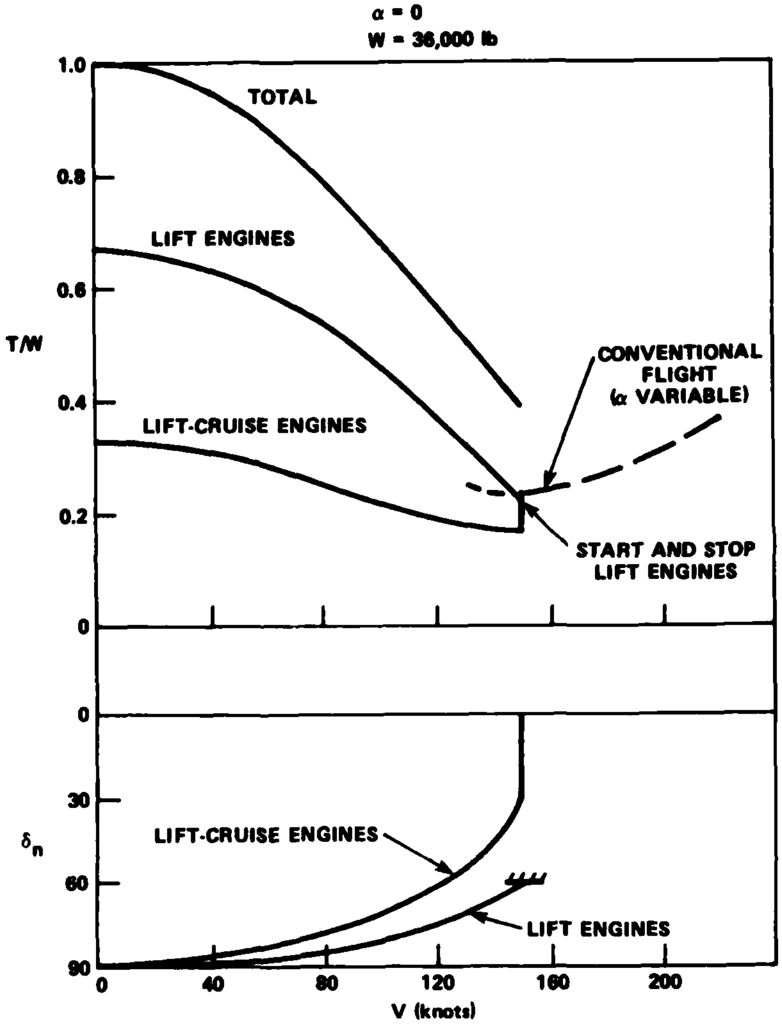


Figure 7 - Thrust and Nozzle Deflection Required for Trimmed Level Flight in Transition

deflection of the wing leading edge and 45 degrees deflection of the flap system is assumed. Conversion from conventional aircraft configuration to the V/STOL configuration would be made at about 150 knots. The lift engines would be started with a nozzle deflection of 60 degrees (30 degrees aft of the vertical) and, to provide longitudinal trim, the ADEN nozzles would deflect the lift-cruise engine thrust 30 degrees as the lift engines started. With the lift engine thrust deflected aft (δ_n=60) and the lift-cruise thrust deflected 30 degrees, about a 30 percent reduction in lift-cruise engine thrust is required for trimmed level flight.

It is proposed that, in transition, a single throttle lever would control both the lift and the lift-cruise engines with the longitudinal control stick dictating the division of thrust between them as required for trim and control. Also, a single nozzle position lever would control both sets of nozzles with a two to one ratio between the deflection of the lift-cruise nozzles and the lift engine nozzles. The pitch control available in transition is shown in Figure 8.

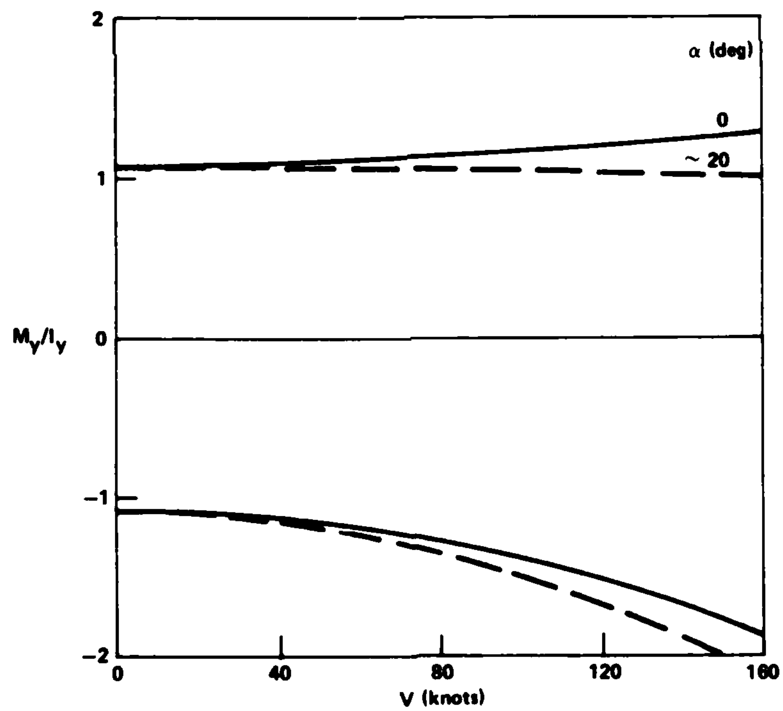


Figure 8 - Pitch Control Available in Transition

Lateral and Directional Control

The lateral and directional control required in *a transition in a 30 knot cross-*wind is compared with the control available in Figure 9. At zero angle of attack, as would normally be used in transition, there is a large control margin available. Even at 20 degrees angle of attack, (which would only be reached in an extreme maneuver situation) where the high dihedral effect greatly increases the roll control required, there is an ample control margin. The aerodynamic characteristics used in these calculations are presented in Figure 10.

Figure 9 - Lateral Control in Transition in a 30 Knot Crosswind, Lift Plus Lift-Cruise Configuration

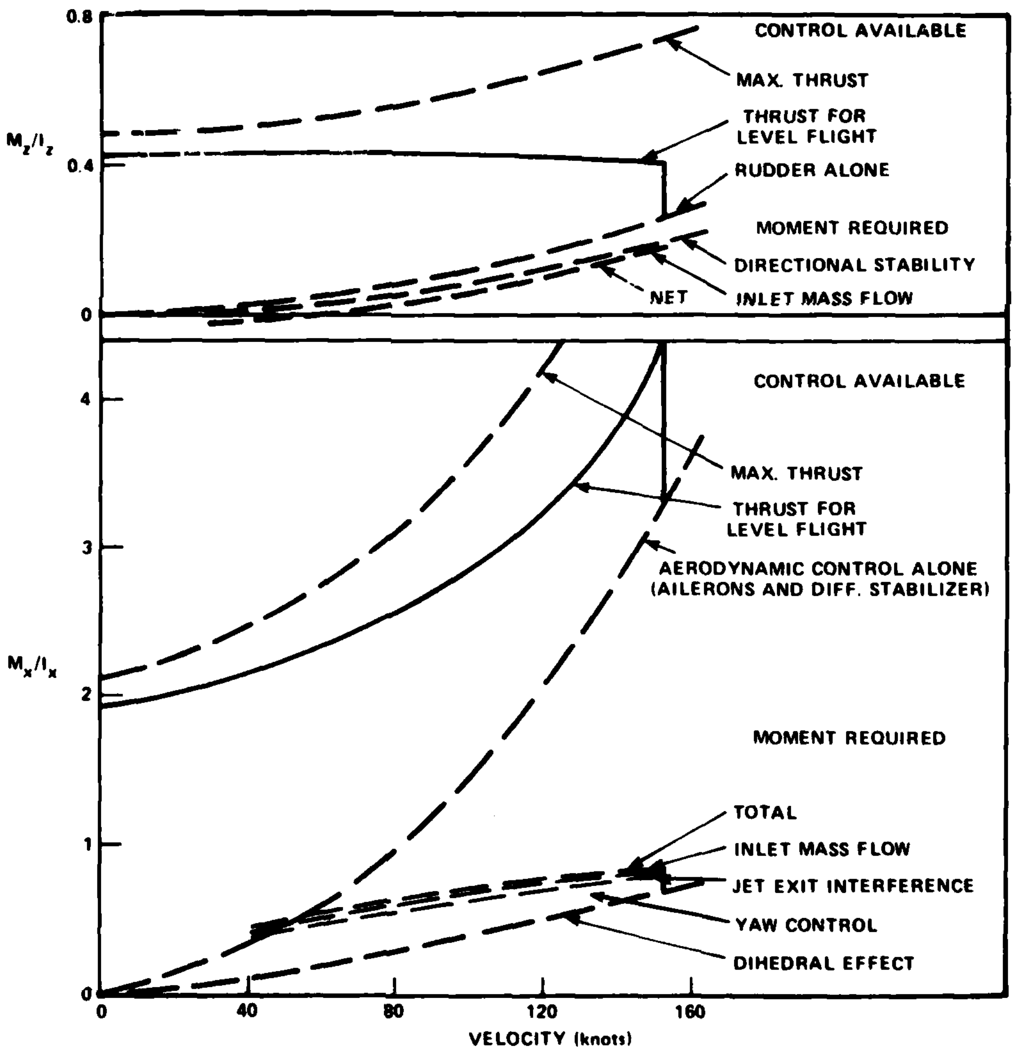


Figure 9a - α = 0 Degrees

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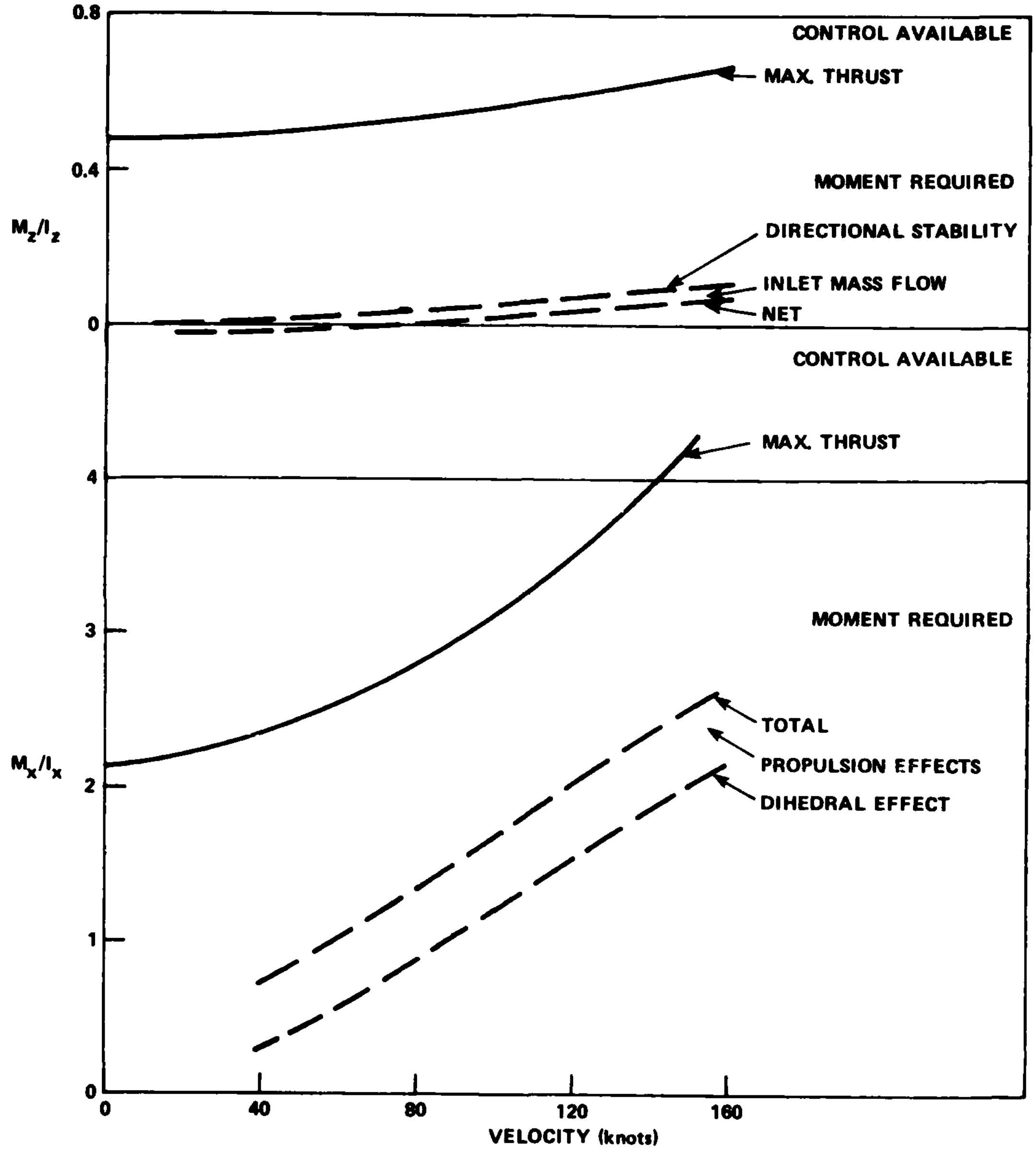

Figure 9b - α = 20 Degrees

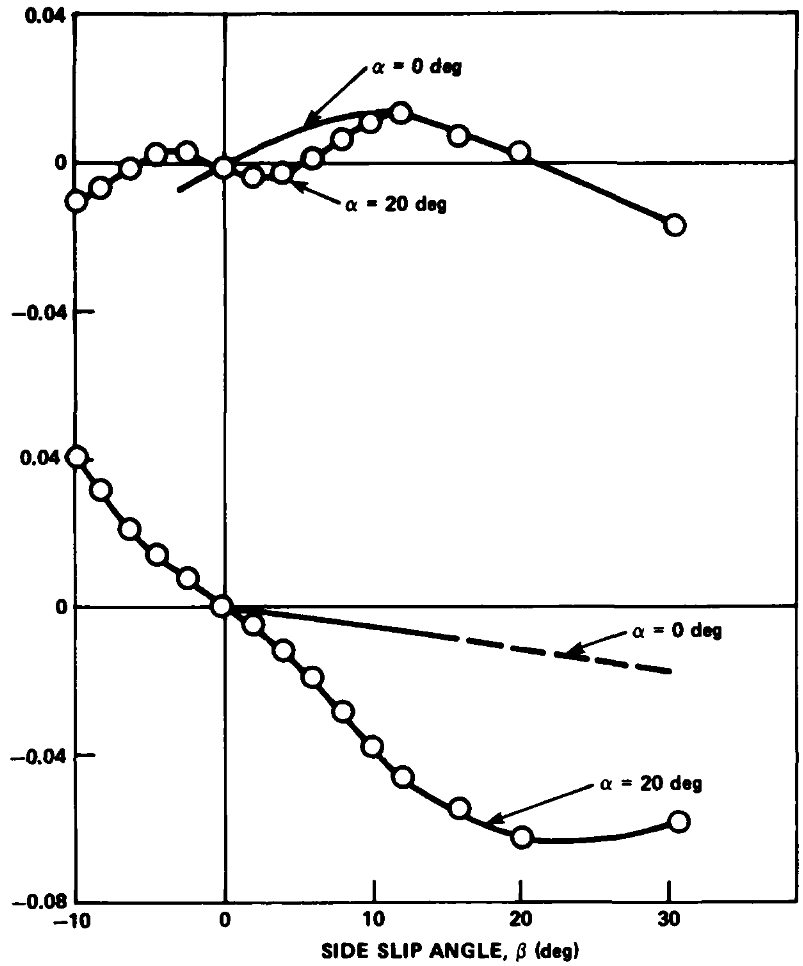

Figure 10 - Lateral and Directional Aerodynamic Characteristics; Approach Configuration

Overload STO Performance

If a short deck run is available, much greater takeoff weights can be lifted as shown in Figure 11. These calculations assume that the takeoff run starts with all engines operating at full thrust (dry), with the lift engine thrust deflected aft 30 degrees (δ_n=60) and the lift-cruise thrust deflected down 30 degrees (for moment trim). At the end of the deck the nozzles are deflected to a preselected setting that depends on the takeoff weight and wind conditions. Climb out is made with sufficient excess thrust to provide 0.1 g longitudinal acceleration and with a 10 percent lift margin. The very large increase in takeoff weight at very short deck runs

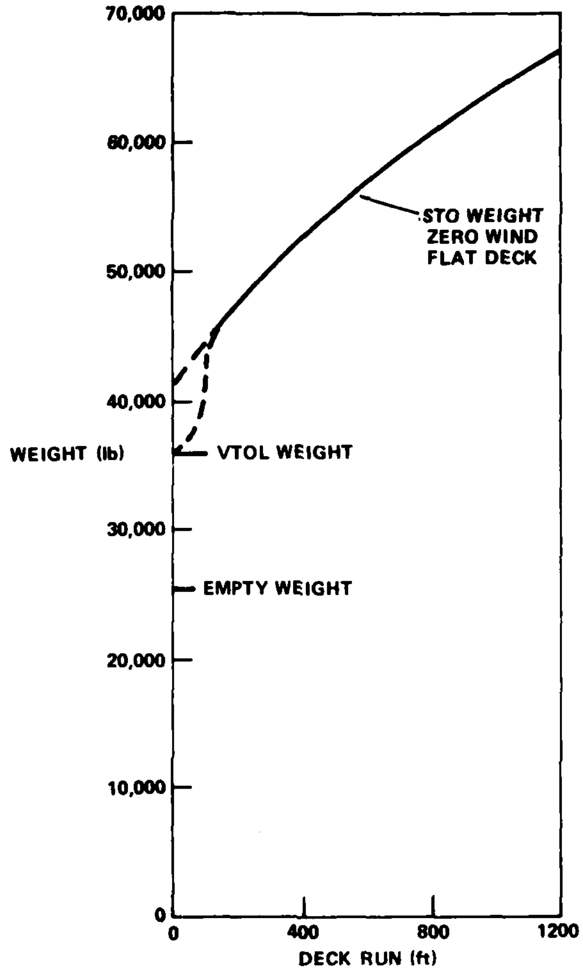

Figure 11 - Overload Takeoff Performance Lift Plus Lift-Cruise Configuration

is due to the elimination of the adverse ground effect (Figure 4) and hot gas ingestion as the aircraft clears the end of the flight deck. These calculations are for zero wind over the deck and for a flat deck. Wind over the deck and a ski jump would both provide further increases in available takeoff weight.

VATOL CONFIGURATION

VTOL Lift

The losses and allowances that reduce the available lift from the rated engine thrust are summarized in Table 4. Because a research and development aircraft to

TABLE 4 - THRUST LOSSES AND ALLOWANCES FOR THE VATOL CONFIGURATION

Thrust (lb)	Operational R and D Aircraft	Fighter
Rated	32,000	36,800 (15 percent growth)
Hot day	30,880	35,512
After inlet and nozzle losses	29,657	34,106
After height control allowance (0.1 g)	26,960	31,000
VTOL Weight (lb)	26,960	31,000

explore and develop the operating techniques and determine the viability of the VATOL concept is needed before an operational fighter is seriously considered, the losses and estimated gross weights of both an operational R and D aircraft and a fighter are presented. Also because an operational aircraft is further in the future it is assumed that a 15 percent growth version of the engine would be available.

With the vertical attitude concept there are no large horizontal surfaces for the adverse ground effects to act on even if the aircraft is hovering over a flat deck. The adverse ground effect is, therefore, eliminated and the hot gas ingestion is greatly reduced and can be eliminated with a properly designed landing platform. The total losses for the VATOL concept are, therefore, much smaller than for a horizontal attitude type.

Weight

A preliminary estimate of the effect of modifications on the aircraft empty weight is presented in Table 5. The empty weight of the two seat TF-18, to be modified to the operational R and D aircraft was assumed to be 600 pounds higher than the basic F-18 VATOL.

Some weight can be saved by deleting the arresting gear tail hook and substituting a conventional main gear for the high sink speed carrier gear. The carrier nose gear is retained to carry the loads imposed by hanging on the landing platform.

Armament provisions and mission avionics can be deleted from the operational R and D aircraft thereby appreciably lowering the empty weight. The operational aircraft, however, would have to carry the mission avionics and armament and be capable of landing with full ammunition and missiles still aboard. The estimate of the probable useful load and fuel available for both the operational R and D aircraft and the fighter is shown in Table 6. The C.G. is estimated to be only 1 to 1.5 inches aft of the CTOL C.G.

TABLE 5 - WEIGHT ESTIMATE FOR THE VATOL CONFIGURATION

	Operational R and D Aircraft (TF-18)		Fighter (F-18)	
CTOL Empty Weight (lb)		22,400		21,800
Delete Tail Hook	-171		-171	
Sub. Conv. Main Gear	-245		-245	
Delete Armament	-354			-416
Delete Mission Avionics	-1200	-1,970		
Add Growth Engines			+400	
Gimbaled Nozzles	+640		+736	
Pilot Tilting	+300		+250	
Aux. Inlet	+50		+50	
Landing Platform Hook	+50	+1,040	+50	+1,486
VATOL Empty Weight (lb)		21,470		22,870

TABLE 6 - FUEL AVAILABLE FOR THE VATOL CONFIGURATION

	Operational R and D Aircraft		Fighter	
Useful Load Available (lb)		5490		8130
Mission Items (lb)				
Crew and Equipment	427		261	
Missiles, Gun, etc.			2191	
Research Instrumentation	200			
Oil and Unusable Fuel	428		470	
Reserve Fuel	1000	2055	1000	3922
Fuel Available (lb)		3435		4208

Transition Performance

The thrust and control deflections required in transition are shown as functions of angle of attack and velocity in Figure 12. The approach configuration consisting of 30 degrees deflection of the wing leading edge and 45 degrees deflection of the flap system is assumed. The aerodynamic characteristics used are presented in Figure 13 and the assumed gearing between the horizontal stabilizer and the nozzles is shown in Figure 14. This gearing, -10 degrees stabilizer at zero nozzle deflection,

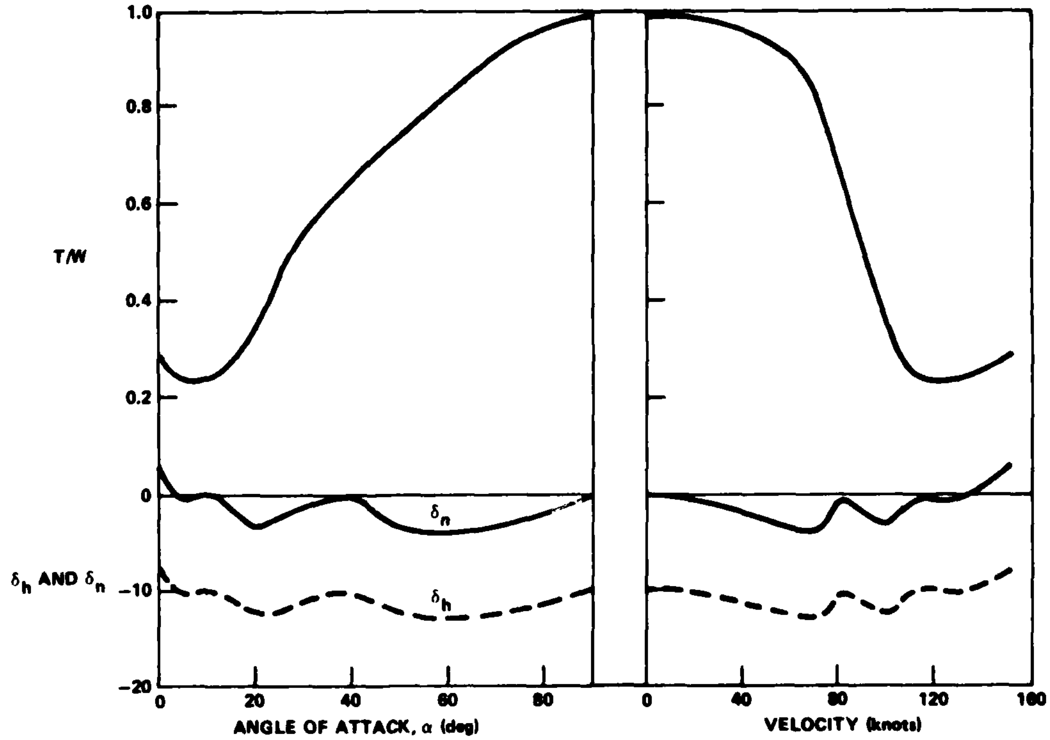

Figure 12 - VATOL Thrust and Control Required in Transition, W = 26,960 Pounds

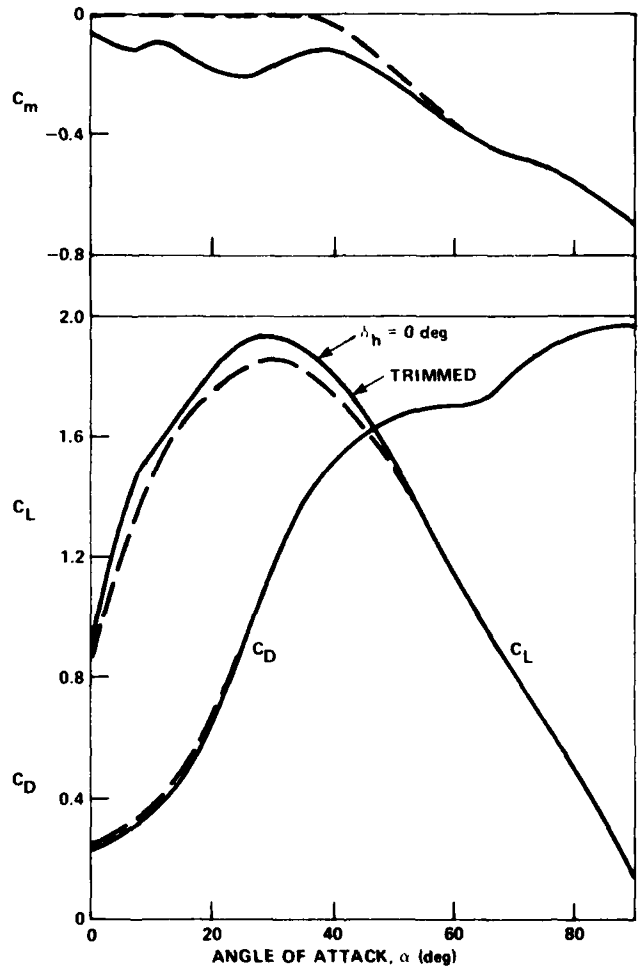

Figure 13 - Longitudinal Characteristics, Approach Configuration

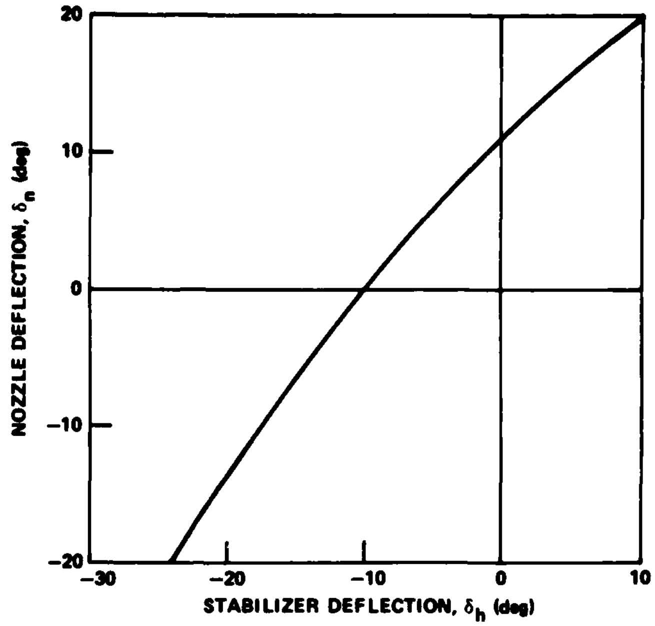

Figure 14 - Assumed Nozzle to Stabilizer Gearing

is chosen to minimize the nozzle deflections required in the lower angle of attack range where large nozzle deflections are required for roll control as will be discussed later At high angles of attack, above 60 degrees, where the stabilizer effectiveness is reduced to almost zero, trim and control are provided by nozzle deflection.

An indication of the fuel required in transition is presented in Figure 15. These calculations for an assumed constant 0.1 g deceleration indicate that 80 seconds are required to transition from zero to 90 degree angle of attack (decelerate from 150 to 0 knots) and about 535 pounds of fuel are required. Afterburner lightoff would occur about halfway through the transition. Fuel consumption in hovering is about 740 pounds per minute. About 2 to 2.5 minutes, requiring 1300 to 1600 pounds of fuel, should be allowed for a complete transition and hookup on the landing platform.

Pitch Control

Pitch control available in hover is shown in Figure 16. The AGARD recommended level of 0.8 radians per square second requires only about 10 degrees nozzle

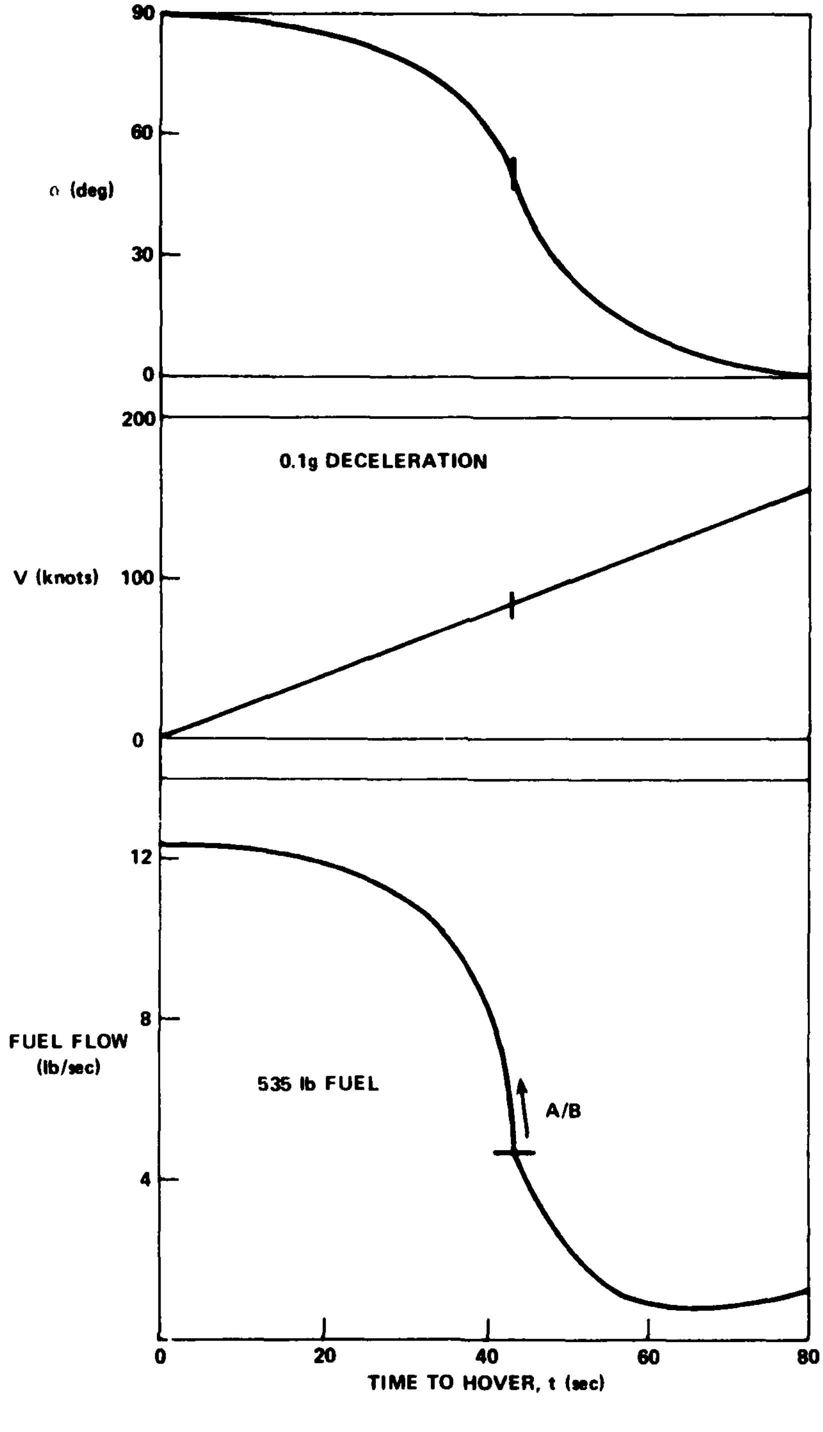

Figure 15 - Fuel Consumption in Decelerating Transition VATOL,
W = 26,960 Pounds

deflection. The higher deflections, up to 26 degrees shown in Figure 3, are required for roll control as discussed in the next section.

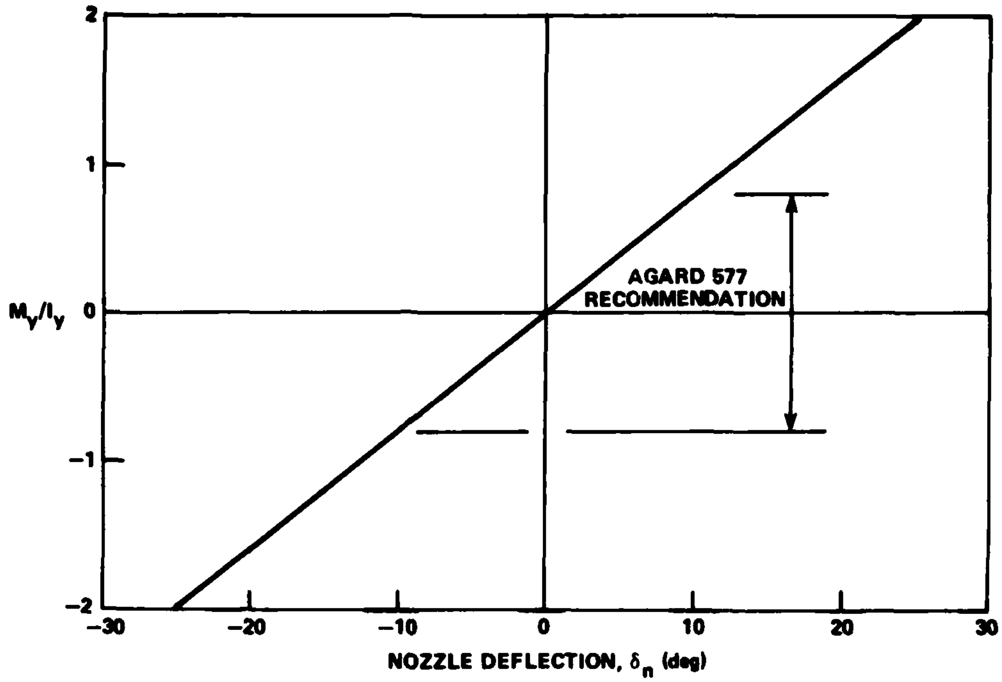

Figure 16 - Hover Pitch Control VATOL Configuration

Lateral and Directional Control

The lateral and directional controls required in a crosswind transition are compared with the control available in Figure 17. A crosswind situation is most critical at the highest angles of attack as the aircraft is leaving or approaching the landing platform and, therefore, may not be in a position to minimize the crosswind component. At the lower angles of attack, approaching conventional flight, the aircraft will be away from obstructions where it can maneuver to minimize the crosswind component. Thus, what appears to be a marginal control situation at 20 degrees angle of attack in Figure 17 should not be a problem; there is ample control margin at crosswind components of 15 knots or less. At higher angles of attack, however, near 60 degrees and above, the control margin available at the thrust for level flight is less than the 0.4 radians per square second desired. The margin at full power, however, may be adequate.

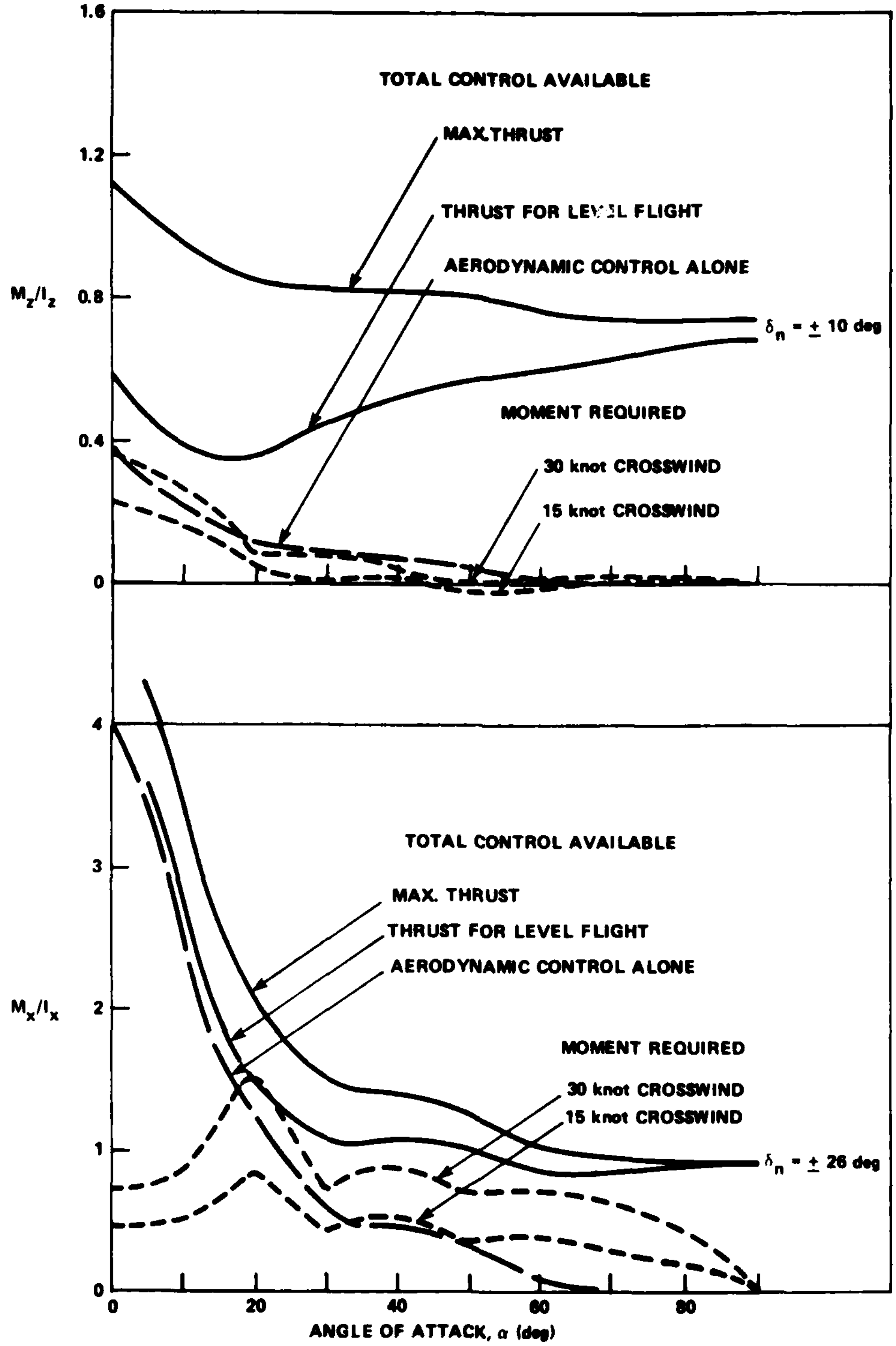

Figure 17 - Lateral and Directional Control in Transition in Crosswind, VATOL Configuration

Roll control could be augmented by using bleed air from the engine ducted to wingtip nozzles. A combination of 5 percent bleed and ±15 degrees nozzle deflection provides a level of roll control that should be fully adequate, Figure 18.

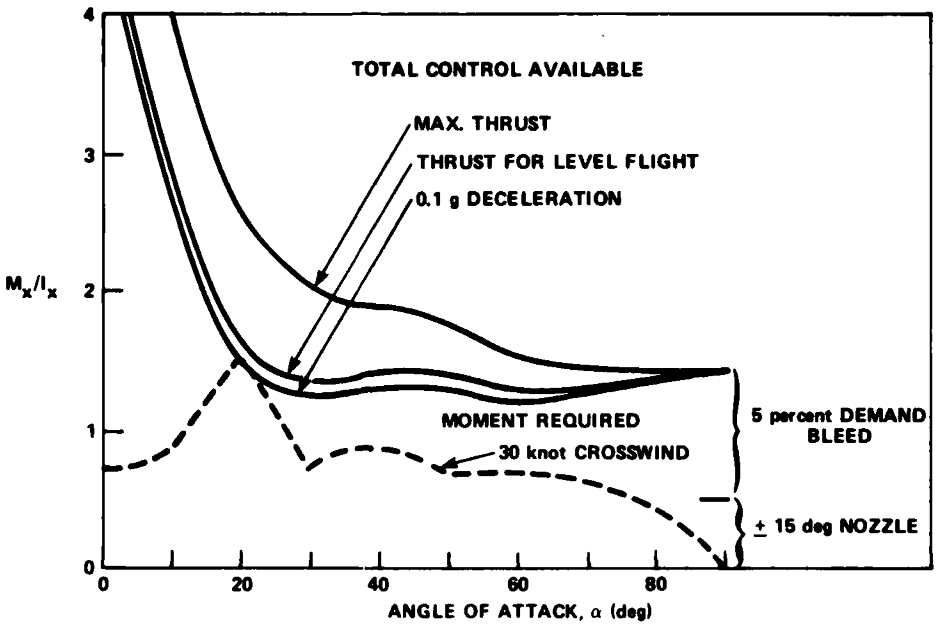

Figure 18 - Alternate Roll Control Concept, VATOL Configuration

Additional analysis, including additional wind tunnel tests at very high angles of attack and manned simulation will be required to determine whether the basic system of differential thrust deflection proposed here will be adequate of if the more complex and costly (in terms of thrust loss) bleed air system must be used.

Yaw control appears to be adequate throughout the transition speed range. The aerodynamic data used in the analysis is given in Figures 19 to 21.

Overload STO Performance

The overload takeoff performance is shown in Figure 22. The calculations assume no wind and zero sink off the deck. Because the VATOL aircraft must be rotated to high angles of attack to achieve equilibrium flight at low speeds and because the deck limits the rotation, the overload takeoff performance from a flat deck is poor. With a ski jump takeoff, however, the rotation takes place after the aircraft leaves the end of the jump and large overloads can be carried from a relatively short deck.

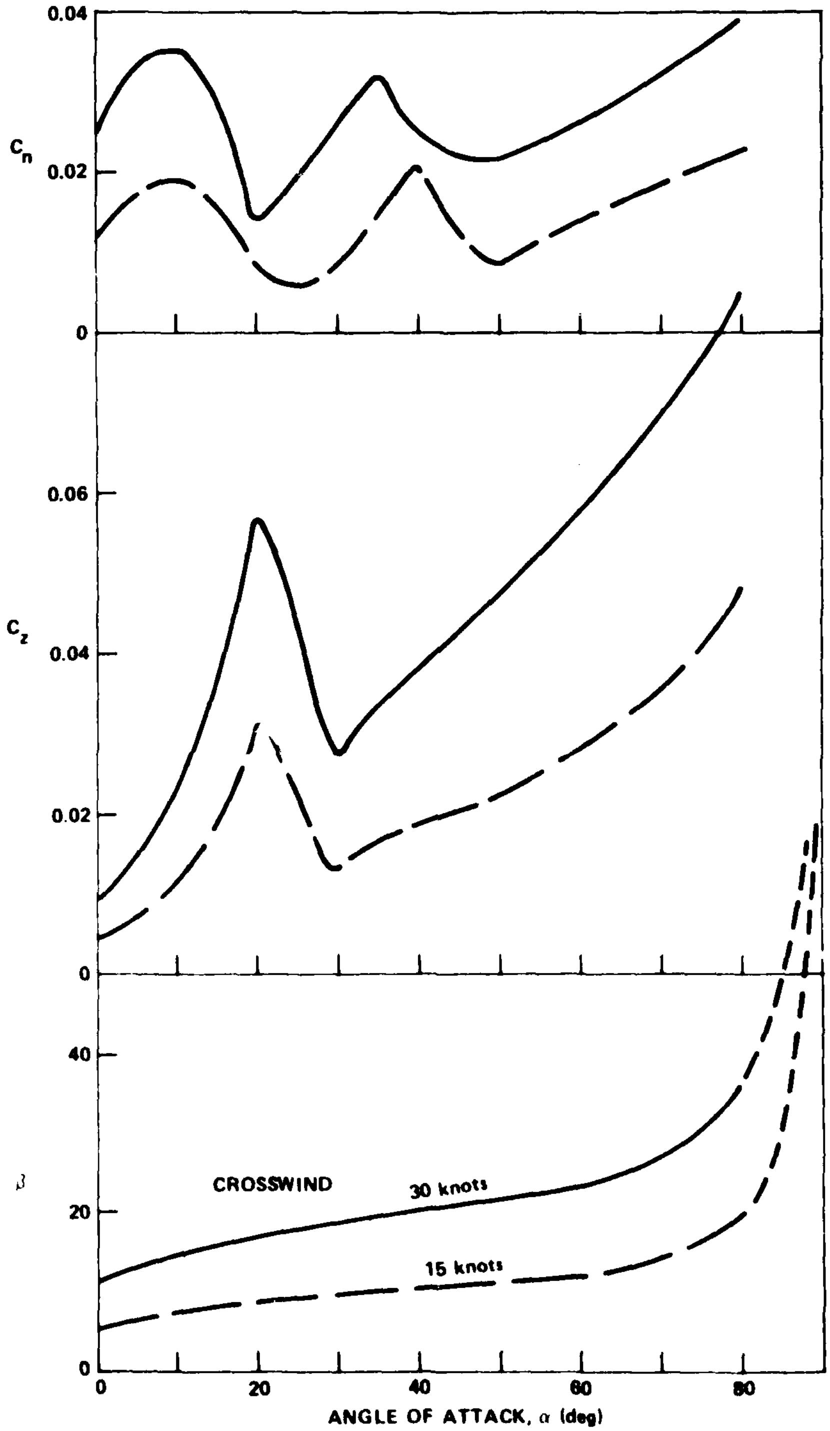

Figure 19 - Rolling and Yawing Moment Coefficients Due to Crosswind

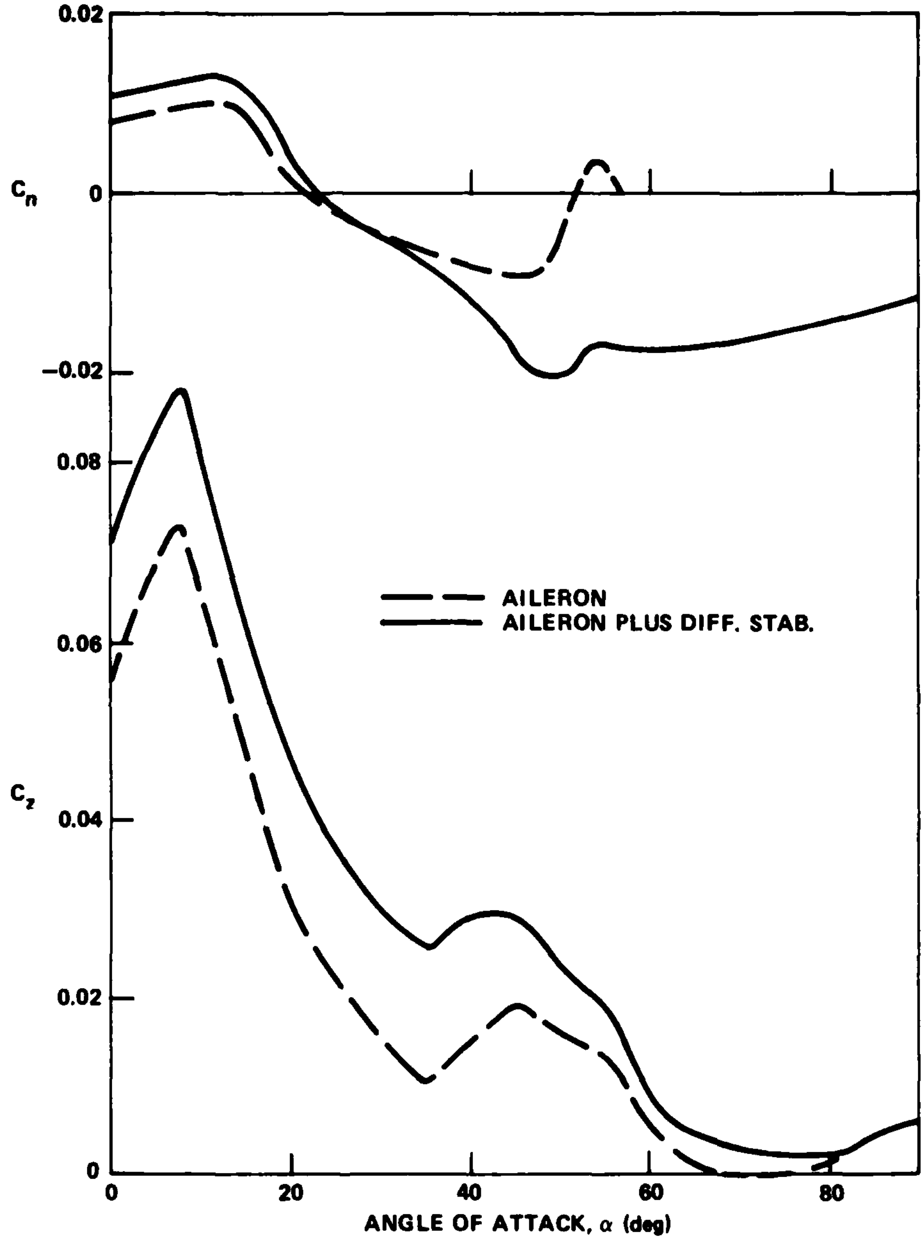

Figure 20 - Aerodynamic Lateral Control

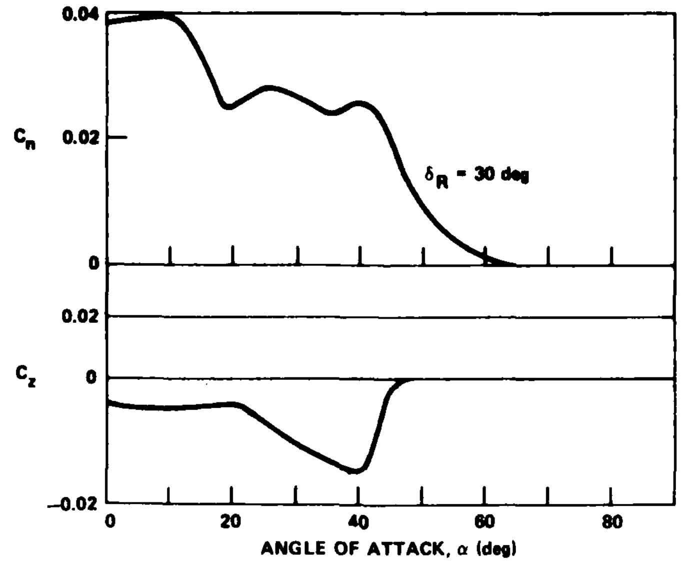

Figure 21 - Aerodynamic Directional Control

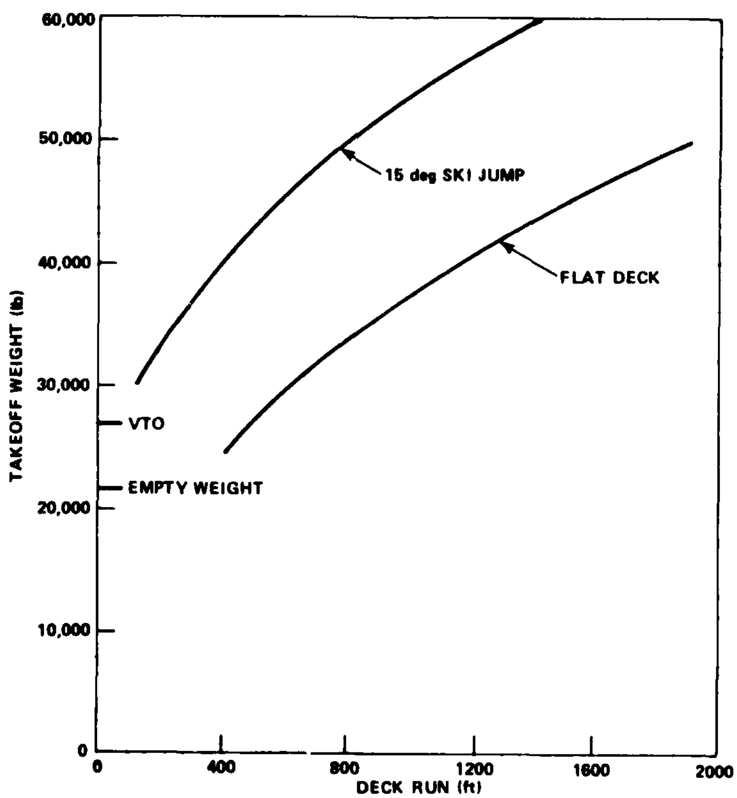

Figure 22 - Overload Takeoff Performance VATOL Configuration, Zero Wind

The calculations assume that equilibrium flight is reached before the vertical momentum imparted by the ski jump is used up. That is, equilibrium is achieved and the climb out starts well above the level of the end of the ramp. If the aircraft were permitted to sink back to deck level even larger overloads could be lifted off.

COMBAT MANEUVERABILITY

Several manned simulation studies[1-3] have shown that augmentation of the conventional control at high angles of attack can greatly increase combat effectiveness. Reference 3 has shown that this augmentation can be provided by the level of control normally used in a V/STOL flight. The aircraft used in the simulation study of Reference 3 was typical of modern fighters in that at high angles of attack it exhibited high dihedral effect and low directional stability. Thus, at high angles of attack rolling into a turn is accomplished by the use of rudder and Reference 3 indicates that augmentation of yaw control at high angles of attack is vital.

The incremental contribution to yaw control available by lateral deflection of the thrust (at maximum power) is presented in Figure 23. The calculations were made for the VATOL configuration but the increments would be only slightly smaller for the lift plus lift-cruise configuration (because of the higher moments of inertia). An example of the total control available (at M=0.8 and 25,000 feet altitude) is presented in Figure 24. A more complete analysis and simulation study should be made to verify that these levels are adequate.

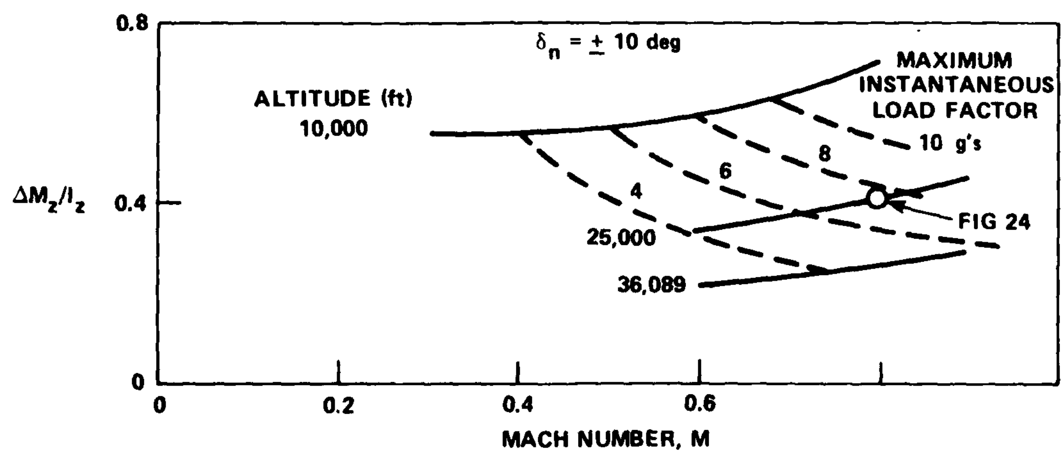

Figure 23 - Effect of Mach Number and Altitude on the Thrust Deflection Contribution to Yaw Control

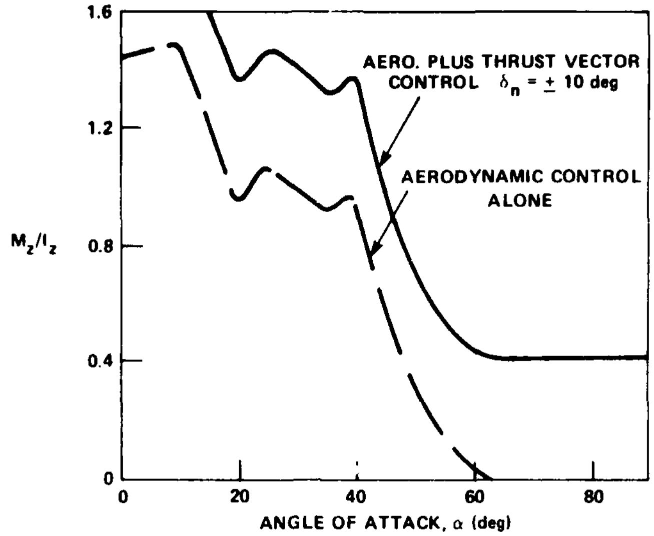

Figure 24 - Example of Total Yaw Control Available, M = 0.8 Alt = 25,000 Feet

DISCUSSION OF MODIFICATIONS AND RISKS

As indicated above, the primary problem standing in the way of immediately proceeding with a VATOL fighter development program are the questions relating to the operational feasibility. The Ryan X-13 and Convair XFY-1 aircraft have shown that VATOL aircraft can be flown through transition. Questions remain, however, about the operational feasibility of the concept in the hands of service pilots operating in field conditions and in all kinds of weather. An operational R and D aircraft is needed to explore the full range of operational problems, to develop and demonstrate solutions and operating techniques, and to determine the operational feasibility and limitations of the VATOL concept.

The lift plus lift-cruise concept, on the other hand, does not need a research aircraft (the VFW-Fokker VAK-191, Donier DO-31, EWR VJ-101, Dassault Mirage III-V, and Bell X-14 lift plus lift-cruise and lift engine research aircraft and Harrier operational experience provide a wealth of background). The lift plus lift-cruise concept, however, requires a lift engine that does not currently exist and requires commitment to an expensive lift engine development program before even a pre-prototype can be built.

The full-scale development of a lift plus lift-cruise configuration should be preceeded by a pre-prototype aircraft which need not include any mission related items but must include all V/STOL related features. The pre-prototype would be used to determine V/STOL performance items such as ground effect and hot gas ingestion and provide a final determination of lift engine sizing. It would also be used to finalize the very important integrated airframe and engine control system.

The primary modifications and developments required for both the VATOL and the lift plus lift-cruise configurations are tabulated in Table 7 and discussed in the next section. The primary modifications and developments required for combat maneuverability enhancement are tabulated in Table 8.

LIFT PLUS LIFT-CRUISE CONFIGURATIONS

Lift Engines

Development and qualification of the lift engines will probably be the most expensive part of the development program of a lift plus lift-cruise aircraft. Past experience with the Rolls Royce RB-162 lift engine series that has been extensively used in V/STOL research aircraft and with the XJ-99 lift engine program, will significantly reduce the risk if further gains in thrust-to-weight ratio beyond the levels attained in these programs are not expected. A bleed rate of 10 percent, as used in the RB-162 family of lift engines, will provide the air required for hover roll control.

Lift Engine Nozzles

Vectoring nozzles have been used on lift engines in the past; notably on the DO-31[6] where nozzle deflection was used for yaw control. A development and qualification effort as part of the lift engine development program will be required.

Lift Engine Inlets

The lift engine inlets must provide good pressure recovery both in hovering and in transition flight and good ram recovery for in-flight starting. These characteristics have been achieved in many previous lift engine V/STOL research aircraft but specific model and full-scale experimental programs are required to ensure satisfactory characteristics with each particular configuration.

TABLE 7 - PRELIMINARY RISK ASSESSMENT

TABLE 7A - LIFT PLUS LIFT-CRUISE V/STOL CONFIGURATION

Item	Development or Modification	Comments on Development Cost/Risk
Lift Engine Installation	Lift Engines	a. Expensive full-scale development and quality program required--based on XJ-99 technology
	Nozzles	c. Development and quality--based on RB-162
	Inlet	c. Develop in wind tunnel
	Fuselage Structure	c. New section behind cockpit
		c. Relocate equipment and modified fuel tank
Cruise Engine Installation	ADEN Nozzles	b. Modify to provide yaw control and quality on F404
	Aft Fuselage Structure	c. Only secondary structure replaced
	Auxiliary Inlets	c. Develop in wind tunnel
		c. Structural modifications between wing and tail main frames
		c. Relocate equipment and modify fuel tank
	Hot Gas Blocking Doors	c. Hinge section of duct wall
Control System: Pitch	Thrust Modulation	b. Integrated engine-airframe control system -High lift engine response rate required -Dissimilar engines
Roll	Bleed Air Ducted to Wingtip Nozzles	c. Relocate equipment in wing and fuselage and integrate with conventional controls
Yaw	Side Vanes on ADEN Nozzle	c. ADEN nozzle modified above integrated with conventional controls

NOTES:

Cost or Risk

a. High
b. Medium
c. Minimum

TABLE 7 (Continued)

TABLE 7B - VATOL CONFIGURATION

Item	Development or Modification	Comments on Development Cost/Risk
Thrust Vectoring Nozzles	Two Axis Gimbals or	b. Extend range to ±26 degrees, or develop and qualify F404
	ADEN	b. Modify to provide yaw control and qualify F404
	Aft Fuselage Structure	c. Only secondary structure replaced
Auxiliary Inlets	Blow-In Doors	c. Develop in wind tunnel
		c. Install between existing frames
Pilot Tilting	Tilting Cockpit	a. Redesign cockpit -Extremely limited space -Commit to fly-by-wire -Simulations needed to define requirements and configuration
Landing Platform Hook	Replace Catapult Launch Arm	c. Loads lower than catapult loads
Landing Platform	Develop and Install on Ship	a. Requires commitment and development
Ski Jump for STO	Install on Ship	c. British have adopted for all carriers

NOTES:

Cost or Risk

a. High
b. Medium
c. Minimum

TABLE 8 - PRELIMINARY RISK ASSESSMENT FOR COMBAT MANEUVERABILITY AUGMENTATION

Item	Development or Modification	Comments on Development Cost/Risk
Cruise Engine Nozzle Installation	ADEN Nozzles	b. Modify to provide yaw control and qualify on F404
	Aft Fuselage Structure	c. Only secondary structure replaced
Control System: Pitch	Existing VEER	c. Integrate with conventional control system
Roll	Existing VEER	
Yaw	New Side Vanes on ADEN	

NOTES:

Cost or Risk

a. High
b. Medium
c. Minimum

Lift-Cruise Engine Nozzles

The ADEN nozzle developed by General Electric has been run at full-scale in afterburner on the G.E. YJ101 engine. A program to scale up this nozzle and qualify it on the G.E. F404 engine in its present configuration should be relatively straightforward. The present configuration, however, does not provide lateral vectoring for either hover yaw control or combat maneuverability. Expanding the development program to include side vanes on the deflector will provide these capabilities and will increase the time and cost but should not be high risk.

Lift-Cruise Engine Auxiliary Inlets

Auxiliary inlets for the lift-cruise engines are needed to provide the additional inlet area required for good static thrust and to minimize hot gas ingestion. The latter requirement suggests that the conventional inlet on the F-18 be closed entirely and that all the air be taken in on the top of the fuselage where the inlet is shielded from the hot fountain flow by the wing and fuselage. This new large inlet is placed aft, just ahead of the engine, to avoid cutting into the main fuselage frames that provide the wing carry-through structure. Experimental programs will be required both statically and at transition speeds to ensure that good pressure recovery with minimum distortion is achieved. Of particular concern will be the vortex flow from the LEX which may be sucked into the inlet. This may require moving the inlet more inboard than shown.

Hover Roll Control System

Engine bleed air ducted to roll control nozzles at the wing tip is used for roll control on the Harrier and has been used on many V/STOL research aircraft. The lift engines can be designed to provide the bleed air required. Developing the roll control system should be straightforward. However, routing the high pressure ducting through the airframe will require relocating other equipment particularly in the wing where the duct will have to be placed between the aft spar of the primary wing box and the flap system. Flap, aileron, and wing fold actuators will have to be relocated, some possibly in external fairings to provide room for the ducting. Also because the wing is very thin, particularly out toward the wing tip, three or four ducts will have to be used to provide the needed flow area.

Integrated Engine and Airframe Control System

Achieving good control characteristics in all regimes of flight will require a high degree of integration of the engine and airframe control systems. This may be the highest risk area of the lift plus lift-cruise development program and will require early and detailed analysis and simulation of the engine and airplane characteristics to ensure good handling qualities.

Pitch control by differential thrust requires rapid engine response. Experience with differential thrust for roll control on the DO-31[6] indicates that the required response rates can be obtained with lift engines but the standard F404 lift-cruise engine will probably not have the response desired. The extent and acceptability of the resulting pitch and heave coupling will have to be evaluated in manned simulations. It should be noted that the DO-31 used only one pitch control nozzle at the tail of the airplane which thrust either up or down to produce the called for pitching moment and, therefore, had pitch and heave coupling which apparently presented no problem.

High Angle of Attack Characteristics

The high angle of attack lateral directional characteristics are very strongly influenced by the flow from the fuselage forebody. Wind-tunnel tests will be required to evaluate the effects of extending the forebody forward 5 feet and to determine the changes to the forebody shape, LEX configuration, and/or control system design required to fix any damage done by extending the forebody. Installing the lift engines and moving the radar, gun, and cockpit sections forward has caused a large forward shift of the center of gravity. Further analysis may indicate the desirability of replacing the LEX with a canard surface to offset the resulting increase in longitudinal stability.

Structural Modifications

Installation of the lift engines will require rebuilding the section of the fuselage between the cockpit and the manufacturing break aft of the cockpit. Installing the lift engines will also require modifying the forward fuel tank and reducing its volume as well as relocating and requalifying some of the avionics and other equipment.

Installation of the auxiliary inlets for the lift-cruise engines will require cutting several fuselage frames between the wing box and the vertical tails and rerouting the load paths around the new openings. It appears, however, that the primary fuselage frames that provide the carry-through structure for the wing and the frames to which the vertical tails are attached can be avoided.

Modifications to the aft fuselage to accommodate the ADEN nozzles only involve secondary structure aft of the primary frames that support the horizontal tail trunions. The new structure will have to provide attachment points and carry the loads imposed by the additional engine mount provided on the ADEN nozzles. In view of the horizontal tail and arresting gear loads for which the aft fuselage structure is designed, additional beefup to carry the nozzle loads will probably not be required but the structure will have to be checked.

Lighter conventional landing gear can be substituted for the present high sink speed carrier gear. The possibility of designing this gear to raise the airplane higher above the ground to alleviate the large adverse ground effect should be considered. Raising the airplane by about 2 feet would reduce the ground effect and increase the VTOL weight by almost 3000 pounds and more than offset the slight increase in gear weight that would be required.

Development Program

The first step in the development program should be a repeat of the present analysis in much greater depth to check and update the above analysis. This analysis should be accompanied by scale model tests to evaluate the ground effect and hot gas ingestion problems, to examine possible fixes, and to provide a first estimate of the sizing of the lift engines.

Manned simulation should also be started early in the program to begin the evaluation and development of the control system and to provide engine response requirements.

The early analysis will have to be supported by preliminary design of the lift engines. Engine development can start once ground effect tests and analysis have given a first cut at lift engine size; however, in view of the difficulty of predicting both ground effect and hot gas ingestion the program should be structured so far as possible to leave some latitude in the final size of the lift engine until after full-scale mockup tests or preferably pre-prototype flight tests have been completed.

Modifying and developing the ADEN nozzles should also start early and should be timed to provide nozzles (not necessarily flight qualified) for the full-scale mock-up tests.

A full-scale mockup incorporating early versions of the lift engines and F404 engines fitted with modified ADEN nozzles should be included in static and wind-tunnel tests as early in the program as possible to refine the ground effect, hot gas ingestion, and transition performance estimates.

The program should include construction and flight tests of at least two pre-prototype aircraft incorporating all V/STOL features but without mission equipment in order to provide "proof of V/STOL performance" data and final sizing of the lift engines as well as to provide a vehicle for fine tuning of the integrated engine and airframe control system.

VATOL CONFIGURATION

Operational Research and Development Aircraft

A flight research program is needed to explore the unique operational problems of the VATOL concept, to develop and demonstrate solutions and operating techniques, and to determine the operational feasibility and limitations of the VATOL concept. This operational R and D aircraft should have two pilots so that the techniques of instrument approach and landing can be explored and developed in safety. It need not carry the mission equipment of the operational aircraft and, therefore, can be lighter and powered with current engines as shown in Tables 5 and 6. It must have all the VATOL unique features, however, including pilot tilting features for both pilots. Provision should be made in the program for possible modification of the research pilots station as may be dictated by the developing needs of the research program.

Pilot Tilting

If the conventional slightly reclined pilot seat were used in the vertical attitude, the pilot would be on his back with his head hanging down. Some method of re-positioning the pilot is required. Simply tilting the seatback forward about 45 degrees proved adequate on the early X-13 and XFY-1 vertical attitude research aircraft. Piloted simulations are required to determine if this will be adequate in an operational aircraft or if some method of tilting each pilot's station is needed. Tilting the pilot's station will make it necessary to go to an all fly-by-wire control system without mechanical backup and rearranging the cockpit so that the stick, pedals, throttles, engine, and essential flight instruments and pilot's seat are contained in a special structure that can be tilted to give the pilot the orientation and visibility required. For the operational R and D aircraft which has two seats, it may be desirable to use both systems. The safety pilot's station would be in front and use the tilting back arrangement so that the mechanical backup control system can be retained. The research pilot would use a tilting crew station which could be altered if necessary during the operational R and D program.

Roll Control System

Manned simulation will be required to develop an adequate roll control system. Differential nozzle deflection would appear to be the simplest system but may be marginal. If differential nozzles must be augmented with bleed air, there will be an impact on the engines in the form of either thrust loss or overtemperature operation. Also the use of bleed air ducted to wing tip nozzles will require modifications in the wing to make room for the ducting and may require mounting some of the flap, aileron, or wing fold actuators in external fairings.

ADEN Nozzles

The current ADEN nozzle configuration includes a variable external expansion ramp (VEER) which can be deflected in the cruise mode. Static tests indicate that the VEER can deflect the thrust down (forward with the aircraft in the vertical attitude) 25 or 30 degrees but only 15 to 20 degrees in the up direction.[7] Thus, the nozzle would be adequate for pitch control in V/STOL operation and probably adequate for both pitch and roll control in combat maneuvering. Modifications and additional development would be required to increase the deflection range to provide adequate differential deflection for roll control in the VATOL mode. Side vanes would have to be added to provide lateral vectoring of the thrust for yaw control but since only about 10 degrees vectoring is required this does not appear to be difficult. An early design and feasibility demonstration of the revised nozzle configuration would be required.

Gimbaled Nozzles

If further analysis indicates that the ADEN nozzles will not be adequate, gimbaled nozzles may be a suitable alternative. There are several designs for dual axis gimbaled nozzles that can be used. However, none have been built and tested to demonstrate adequate operation and cooling. Also, the design deflection range is only ± 15 degrees. Increasing the "sphere" diameter to increase the deflection to ± 26 degrees appears possible but cooling problems will increase. If differential nozzle deflection is determined to be adequate for roll control, an early design and feasibility demonstration of the large deflection range needed would be required.

Uprated Engines

The operational fighter would use a ski jump in order to take off with enough fuel and payload for a mission but would land on the VATOL platform. It must have enough thrust to support the landing weight which will include all mission equipment including nonjetisoned expensive stores and sufficient fuel for the approach and landing. An uprated engine will be required and a 15 percent growth version of the current engine is assumed in this study (Tables 4 through 6). Significant further growth of the engines may, however, be severely limited by the constriction on the inlet duct size available. The inlet duct passes through the fuselage main frames that provide the carrythrough structure for the wings. Increasing the duct size to carry additional mass flow would require a complete rebuilding of the wing and fuselage center section.

Integrated Engine and Airframe Control System

An integrated engine and airframe control system will be required but the development should be much simpler than for the lift plus lift-cruise concept because all control is by thrust vectoring (or perhaps bleed air for roll control) and thrust modulation is required only for height control where the time constants required are attainable with conventional engines.

Auxiliary Inlets

Installation of blow-in doors to provide the inlet area required for good static thrust pressure recovery does not involve any primary structure. In fact it may be possible to install the blow-in doors between existing inlet structure frames. Static and wind-tunnel tests will be required to develop the configuration.

Structural Modifications

In addition to the inlet modifications discussed above, modifications to the aft fuselage structure to accommodate the vectoring nozzles will be required. These modifications, however, will only involve secondary structure aft of the primary frames that support the horizontal tail trunions. The new structure will have to provide attachment points and carry the loads imposed by thrust vectoring. In view of the horizontal tail and arresting gear loads for which the aft fuselage structure is designed, additional beefup to carry the nozzle loads will probably not be required but the structure will have to be checked.

Landing Platform Hook

It is anticipated, as indicated in Reference 4, that the landing platform will contain a grid of cables which will be engaged by a special hook deployed from the nose gear when the VATOL aircraft lands. On the VATOL conversion of the F-18, this special landing platform hook can be installed in place of the catapult launch bar on the present nose gear. Additional modifications to the nose gear should not be necessary because the loads involved in landing and hanging on the landing platform should be much less than the loads imposed on the nose gear by a catapult launch.

Landing Platform

The X-13 used a single cable supported by two arms projecting from a truck bed that had been elevated to the vertical as a landing platform. Subsequent studies[4] have proposed concepts such as a grid of cables on a wider platform that hopefully reduces the precision required in the hookup. One point that will be crucial in both the design of the landing platform and in the solution of the pilot tilting problem will be to give the pilot adequate visual cues as to his position with respect to the hookup point. Manned simulations with mockups of the landing platform, the cockpit, the hook-on devices, and all features important to visual cues will be required before the final choice of landing platform is made.

Ski Jump

An operational VATOL F-18 will require a ski-jump takeoff in order to carry enough fuel to perform a useful mission. The ski-jump concept has been proven with the Harrier and is being installed on all British Navy carriers.

Development Program

The development of the VATOL concept requires first of all a research program with an operational R and D aircraft to explore the unique operating problems of the concept and to develop and demonstrate solutions and operating techniques and to determine the operational feasibility of the VATOL concept.

The first step in the development of a VATOL operational R and D aircraft should be a repeat of the present analysis in much greater depth to check and update the findings. This analysis should be accompanied by manned simulations to evaluate the roll control problem and determine whether differential nozzle deflection can provide adequate roll control or if nozzle deflection will have to be augmented by bleed air from the engines. Many of the details of the remainder of the development program will depend on this result.

A second manned simulation effort will be required early to resolve issues in the area for pilot tilting and landing platform design. This simulation will include a mockup of the crew stations and the landing platform including all visual cue aspects as well as the hook up device.

The development of the nozzles can be initiated after the roll control question is resolved and the control system requirements are determined.

The question of whether or not a pre-prototype aircraft program is required (assuming the operational R and D aircraft results have led to a decision to proceed to an operational VATOL fighter) will depend on the extent to which the projected fighter differs from the operational R and D aircraft. If there are little or no differences in the VATOL features, the program could proceed directly to a full-scale development prototype.

EFFECTS ON PERFORMANCE

LIFT PLUS LIFT-CRUISE CONFIGURATION

Several factors that can increase the drag of the lift plus lift-cruise configuration. Extending the fuselage forward increases the skin friction drag, the forward movement of the C.G. increases the trim drag, and the higher empty weight means that for a given mission the aircraft will be flying at a higher weight with higher induced drag for part of the mission. Also, the reduction in internal fuel due to the lift engine reducing the forward tank volume and the auxiliary inlets reducing the volume of the rear tank means that for long range missions more external fuel will have to be carried. On the other hand, replacement of the axisymmetric nozzles with two-dimensional nozzles may reduce the afterbody drag. The net effect will be a reduction in range but the increment lost has not been estimated.

The ADEN nozzles include a variable external expansion ramp (VEER) which can be used to vector the thrust in the vertical plane in cruise and combat. Vectoring both engines together will augment pitch control and differentially will augment roll control for enhanced combat maneuverability. An additional set of vanes will have to be developed to provide lateral vectoring to augment yaw control, the most important axis.

VATOL CONFIGURATION

The only significant change on the VATOL configuration that will affect drag is the modification of the aft end lines of the fuselage to incorportate the new nozzles. Both the weight and the C.G. change are small.

The V/STOL control system, symmetrical deflection of the thrust for pitch control, differential deflection for roll control and lateral deflection for yaw control, can also be used without modification to augment the conventional controls for improved combat maneuverability.

CONCLUDING REMARKS

This brief conceptual study indicates that the F-18 could be modified to either a VATOL or a lift plus lift-cruise V/STOL configuration. The lift-cruise plus remote burner concept does not appear compatible with the basic F-18 airframe.

The VATOL concept requires the least modification to the basic airframe but would require a ski-jump takeoff in order to lift off enough fuel and payload for a useful mission. Also, because the VATOL concept involves a unique operational mode requiring flying the airplane through the stall and progressively tilting the pilot so that adequate visual cues can be maintained, an operational R and D aircraft is required. This aircraft would be used to explore the operational problems as they apply to service pilots in fleet operations, to develop and demonstrate solutions, and to determine the operational feasibility and limitations of the VATOL concept.

The lift plus lift-cruise concept can be configured to lift enough useful load for short range missions in the vertical takeoff mode and much greater loads with a short takeoff even from a flat deck. The lift engines required, however, are not available and an expensive development program would be required. Because of the extensive past experience with lift engine and lift plus lift-cruise test beds, and horizontal attitude takeoff V/STOL's in general, a research aircraft of this concept is not required. However, the program should include a pre-prototype to be used to verify and fine tune the V/STOL performance and to provide a final integrated airframe and engine control system.

The ADEN nozzle currently under development can be used, with some modification, to improve the combat maneuverability. Because combat maneuverability enhancement does not require any of the other V/STOL modifications and because combat maneuverability enhancement is of interest in its own right, a program to modify an F-18 to incorporate the ADEN nozzles and flight demonstrate the combat advantages would appear to be a logical first step. Further modifications to incorporate a vertical capability should then follow.

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